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AGRICULTURE

By WILLIAM SOMERVILLE, M.A., D.Sc.

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PREFACE

THE object of this volume is to discuss the fundamental principles underlying the practice of agriculture. It is, in the main, an introduction to crops and cropping, and contains the sort of information that a farmer may be expected to possess who aims at cultivating his fields and manuring his crops intelligently. The special requirements of the readers for whom the series is intended have constantly been borne in mind; and it is hoped that, supplemented by the selection of the works mentioned at the end, the little volume may be useful for those who have to gather their knowledge without much aid from laboratories and lecture rooms.

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AGRICULTURE

CHAPTER I

THE FORMATION OF SOIL

IN approaching the study of agriculture one finds that the subject naturally arranges itself in a certain order, which can perhaps best be traced by working backwards. Live stock presuppose crops, and these imply considerations of tillage, tending, and harvesting. Before, however, a crop is sowed or planted, a farmer has given consideration to seed, manures, and the sequence of crops. Then, again, in many cases land cannot be cropped till it has undergone an ameliorative process, such as liming or draining; and finally we get back to the soil itself, with its varied properties and complex origin.

Beginning, therefore, with the soil, and working up to the crop, we may first of all look at what soil is and how it has been formed.

If we go back far enough in the history of the earth we reach a time when there can have been no soil, for the reason that there was not even rock from which to form it. The theory with regard to the evolution of our earth, that finds most acceptance, assumes that at one time it was subjected to so high a temperature that everything of which it is composed was in a state of vapour. In the course of ages, as heat was lost, many substances hitherto held in a state of vapour became liquefied, and at this stage we can imagine a globe of essentially the same shape as at present, but in a more or less plastic condition, and containing no atmosphere as we understand the term. Gradually, as more heat was lost, the surface of this semi-fluid mass solidified, and, as cooling proceeded further, the superficial crust became thicker. When the temperature fell sufficiently it was possible for some of the water vapour to assume the liquid form, and directly this point was reached the formation of soil became possible. Hitherto the rocks composing the earth were all of the class called igneous, that is to say, they had crystallized out of a molten mass, or were of the ashy character of which lava is a modern representative. But directly water assumed the liquid form it

collected in the hollows to form seas and lakes, or flowed off the surface by whatever channels offered the opportunity of movement. Such flowing water eroded the solid rock, as streams do at the present time, and the particles thus involved in the current were ultimately deposited in lakes and seas. These deposits in the course of time hardened to form what are called sedimentary rocks, which now constitute a large part of the earth's crust. But it is well to remember that the inorganic constituents of such rocks have all been derived directly or indirectly from igneous rocks. Sedimentary rocks, formed directly from igneous rocks, have often in their turn been attacked by running water, and their constituents, re-sorted in the shape of sand, grit, and silt, have been dropped in the estuaries of rivers and streams, again to form sedimentary rocks.

If we dig into the earth's surface at any point it is not long till we pass through the superficial soil and reach harder material. The transition from soil to the harder material underneath is generally more or less gradual ; and, having reached the subsoil, we become aware, as we go deeper, that even the subsoil is softer above than below, until at a depth of, it may be, a foot or two we reach practically

solid rock. From such solid rock, whether it be igneous or sedimentary, the soil that we cultivate in our fields has all been derived, sometimes directly, in other cases through the agency of running water, as in the case of alluvial soils.

The sequence of changes from solid rock to cultivated soil can be best studied by inspecting a section that is exposed in the operations of quarrying. Proceeding upwards, we find that immediately over the solid rock there are large masses of stone with but little soil between them. These stones were at one time part of the solid rock, but, by the operations of certain weathering agents, they have become detached from the main body of rock. As we go farther up we find that the stones become scarcer and smaller in size, so that the spaces between the stones are larger and the volume of soil greater. Then, still farther up, the stones are even smaller and fewer, and in the top 8 or 10 inches—which is the material stirred by the plough and other agricultural implements—large stones may be entirely absent or difficult to find.

This gradual conversion of solid rock into tillage soil is brought about by the operations of natural forces, few in number and

simple in character. These so-called weathering agents may be grouped as follows :—

First, variations of temperature—in other words, the lower temperature of winter as compared with summer, and the greater warmth of the day as compared with the night—have had much to do with the breaking up of rocks and the disintegration of stones. This result would not have followed, to any great extent, if rocks and stones were absolutely uniform throughout; but this is far from being the case, most stones, and the rocks from which they have been derived, being complex in composition and containing many substances. One of the simpler rocks is granite, the main constituents of which are quartz, felspar, and mica, and these three substances show varying degrees of expansion and contraction under changes of temperature, that is to say, they do not all expand and contract equally. It is evident, therefore, that, even if a rock hold no more than two or three substances, there must be a strong tendency for the constituents to work apart, so that cracks or fine fissures are formed where the different substances come into contact. Whenever a rock or stone is no longer solid, but is traversed more or less by a network of fissures, even if they are so fine as

hardly to be seen, a stage has been reached when the operations of other weathering agents become possible. Hitherto, water, for instance, has been unable to penetrate the mass, and, although it may have been operative on the surface, its power of dissolving the constituents of the rock or stone has been but limited. But directly water is permitted to gain access to the interior, its power as a weathering agent is greatly increased. Water acts in various ways in the formation of soil. In the first place it is an almost universal solvent, so much so that there are few substances that it cannot attack and dissolve to a greater or less extent; and it is evident that if some substance easy of solution is removed from a rock or stone, the rock or stone is honeycombed and weakened in the process, and its power of resistance to other forces is correspondingly diminished. But water also acts chemically upon rocks, converting certain constituents which have no water in their composition into compounds in which water plays an essential part. This change is called by chemists "hydration," and can be illustrated by various familiar examples. One can, for instance, take as an illustration the slaking, or, as a chemist would say, the hydration of lime. Every one

knows that when freshly burned lime is brought into contact with water it absorbs a certain amount, and in the process swells up, and finally crumbles down into a dusty, powdery mass. The water, as such, has disappeared, that is to say, we might add a gallon of water to a heap of burned lime, and although the water was manifestly absorbed by the lime we should be left with lime as dry as the substance with which we started. A small proportion of the water may have escaped into the air in the form of vapour, but most has been taken up by the lime to form a new chemical compound. We start with what is known chemically as oxide of lime, or anhydrous calcium oxide, a substance containing only calcium and oxygen, and we end with a substance which the chemist calls hydrated lime, which is still calcium oxide but now united chemically with a certain amount of water. During this change two things are to be noted, the one, that the lime has undergone considerable increase in volume, and the other, that it has crumbled down in the process. That the slaking of lime is accompanied by increase in volume is evident from various familiar examples. For instance, if we fill a pail with lime shells and pour water upon it, we find that when the lime

is slaked the pail is no longer able to contain it. Sometimes a farmer has an illustration thrust upon his notice when he purchases lime for agricultural purposes. The railway waggon is filled at the lime-kiln, and is probably dispatched unprotected by a waterproof covering. During the journey, occupying a day or more, heavy rain may fall, and the lime will be more or less slaked, so that when the waggon arrives at its destination it may be found that a considerable amount of lime has been spilt on the journey through swelling up and falling over the side of the waggon. Many other substances besides lime are capable of combining with water in a similar manner, and some of them are present in rocks. One such substance is calcium sulphate, which like lime is capable of chemically combining with water, and in the process is converted into the material called gypsum, undergoing in the change considerable increase in volume. Rocks also in many cases contain what are called anhydrous silicates, namely, substances holding silica in combination with some other material, but possessing no water. These silicates can, like burned lime, absorb water and increase in volume; and it is evident that if a rock contains any such substance it will be rapidly

disintegrated, provided water can gain access to its interior. Such entrance of water is facilitated by the cracks that are formed as a result of the unequal expansion and contraction that is associated with variations of temperature.

Water also acts powerfully as a disrupting agent through the agency of frost. A vessel may contain water without injury, but a different result will ensue if the water is subjected to a temperature sufficiently low to convert it into ice. During the change the volume of the water is materially increased, and so powerful is the pressure thus set up that no ordinary vessel is able to resist it. The result is seen in the bursting of water-pipes, and in similar phenomena.

Directly water enters a stone to fill up the interstices, the fate of that stone depends upon the occurrence of frost. So long as the water remains in a liquid form its effect is but slow, but whenever it is converted into ice the parts of the stone are pushed asunder, and when a thaw comes, and the ice is reconverted into water, the hardest stone may crumble down into a shapeless mass. This effect of water is undoubtedly one of the most powerful agencies in the formation of soil.

In considering the part played by water, mention must also be made of its action as an eroding agent. No one can visit a hilly district where streams are abundant without observing that they flow in well-defined channels, and one may also sometimes find that they have cut a narrow passage in the solid rock. So long as the water is clear, its power of deepening its passage is but limited; but directly a stream becomes turbid, that is to say, as soon as it carries solid material in suspension, its power of erosion is greatly increased. Streams, which when at summer level are comparatively placid, may, during times of flood, become raging torrents, carrying with them large stones and rock débris. Movement of such bodies over the stream's bed is accompanied by great erosion, and the particles knocked off the stones themselves, or detached from the rocky bottom, are borne along by the water, to be deposited under quieter conditions, such as prevail in a lake or in the sea, or on the fields (haughs) which the flood may reach. The silt so deposited forms alluvial soil, which in many cases is highly fertile.

Another of the natural agencies at work in disintegrating rocks and stones and producing soil is oxygen. This gas, which is

present in the atmosphere to the extent of about twenty-one per cent., has the power of uniting chemically with most substances, the result in many cases being the destruction of the body thus affected. The destructive action of oxygen is illustrated in the process of ordinary combustion, as, for example, where a heap of thorns is consumed by fire. But destruction though slower is no less complete where the process is not associated with visible fire. Iron, for instance, when exposed to the atmosphere, corrodes and becomes rusty, the conversion of metallic iron into rust being essentially of the same character as the destruction of a heap of brushwood by fire. Whereas iron is a highly resistant body, the rust which oxygen forms is easily crumbled and is markedly non-resistant. Not only may pure substances like iron combine with oxygen and be converted into what chemists call oxides, but certain compounds, *e.g.* sulphides, may unite with more or less oxygen and be converted into other compounds, as, for instance, sulphates. In stones and rocks there are many substances which can combine with oxygen, and the compound so formed is in most cases easily disintegrated, as compared with the original material. If

one examines a heap of rough land-gathered stones lying by a roadside, one will often find that they are more or less yellow or red on the surface. When they are broken in the process of preparation as road-metal, it is possible to trace a gradual transition from the red, friable surface to a dark, crystalline centre. The dark centre is comparatively unoxidised, whereas the outer layers of the stone have been in contact with the oxygen of the air, which has entered into combination with, amongst other things, the iron that is present in the mass. The result of such combination is the formation of rust, or of some other form of iron oxide, whose friability greatly assists the conversion of the stone into soil.

One of the most powerful weathering agents is carbonic acid gas. This substance acts chiefly through the increased power of solution that it imparts to water. Whereas pure water will dissolve most things, it dissolves them in many cases very slowly, but when water is charged with carbonic acid gas its power of dissolving all bodies, including the constituents of rocks, is greatly increased. Compared with oxygen or nitrogen, carbonic acid gas is extremely soluble in water, that is to say, a given volume

of water can absorb and retain a large proportion of this gas. The water in the soil obtains its carbonic acid gas in various ways. In the first place, in falling through the air, rain-water dissolves a certain amount of this gas, which it carries in solution to the soil, where it comes into contact with the stones and rocks. In proportion to the amount of oxygen and nitrogen present in the atmosphere, the quantity of carbonic acid gas is very small, but, as the affinity of water for carbonic acid gas is very much greater than for the other constituents of the atmosphere, it follows that the gaseous substances dissolved from the atmosphere by the falling rain are relatively much richer in carbonic acid gas than the atmosphere from which they have been derived.

The water in the soil, however, derives the bulk of its carbonic acid gas from the supplies which are liberated during the oxidation of vegetable matter in the soil. Soil always contains more or less vegetable matter, and in many cases a large amount is present, as, for instance, where soil is rich in humus, derived, it may be, from peat, or from decomposing turf, or from the residues of previous crops, or from farmyard manure. These organic substances, calculated dry, generally

contain about fifty per cent. of carbon, and in the process of decay this element unites with oxygen to form carbonic acid gas. The air present in the interstices of the soil, therefore, is specially rich in this gas, and water in the soil has full opportunity of taking up such gas and of thereby adding to its powers of solution. Other things being equal, there is little doubt that the more carbonic acid gas there is present in the soil the greater is the amount of plant food available for the use of crops, such liberation of plant food being effected through the agency of water charged with this gas. Not only are such substances as potash and phosphates dissolved from the stones and rocks, and rendered available for the use of plants, through the agency of carbonic acid, but even when applied as manures these same substances are more effective in the presence of considerable supplies of carbonic acid.

An agency that must be mentioned in connection with the formation of soil is plant roots, which break down stones and rocks in two ways. In the first place they push their way into the cracks and minute fissures of stones and rocks, and, having gained an entrance, they grow, and exert

considerable disruptive force. The breaking down of rocks and stones in this way is a purely mechanical process. But plant roots also assist in the formation of soil by parting at their apex with an acid fluid—largely carbonic acid—which attacks stones and rocks, and assists in the solution of their contents.

Over large areas in the British Isles the soil of our fields owes its origin to the action of glaciers, which at one time filled our valleys to the depth of hundreds of feet. With the exception of the higher mountain ranges, the whole of Great Britain and Ireland was heavily glaciated as far south as the Valley of the Thames. By the action of the moving ice the hills were rounded off and planed down, while the valleys were deepened, the whole process being accompanied by severe attrition, the material so rubbed off being deposited in the plains and valleys. If one digs into a field in many parts of the country, especially in the North, one soon comes upon a stratum consisting of larger or smaller stones, often smoothed, and of very diverse character, such as limestone, shale, sandstone, granite, whinstone, and even coal. These stones and boulders, which had, in some cases, been carried by the ice for hundreds

of miles, are intermixed with finer material, such as clay and grit. When the ice-sheet melted, and this boulder-clay became exposed to the weather, its upper layers underwent the weathering changes that have just been described, the result being the soil that we till on many of our fields, which rests on a subsoil of glacial material in much the same condition as the glaciers left it thousands of years ago.

CHAPTER II

THE PROPERTIES OF SOIL

HAVING briefly considered the formation of soil, we may now conveniently turn to certain physical and chemical properties that it possesses, which are of much importance in their bearings on the nutrition of plants and the cultivation of farm crops.

One property that soil has is simply the power possessed by the particles of sticking together, or, as it is called, the property of cohesion. At one end of the scale we have dry sand, which is practically destitute of cohesiveness; while the other extreme is occupied by plastic clay, which exhibits so

much cohesiveness that it can be moulded into any shape that we may desire. As so often happens, the best conditions, from the agricultural point of view, are not to be met with at either extreme, in fact a soil with little or no cohesiveness is almost as profitless a subject as one of the consistency of Gault Clay. When a soil possessing too little cohesiveness is taken in hand for purposes of cultivation, the first step taken by the farmer or gardener is to introduce something into the soil that will give it "body," and assist in keeping the particles together. Sandy soil can be improved by the addition of clay, and at one time the operation of "claying" land, in other words the admixture of fifty loads or more per acre of clay with the surface soil, was not an uncommon ameliorative process. But such an operation involved more outlay for labour than is justifiable under present conditions, so that, except under very exceptional circumstances, one does not now find that sandy soil is being treated in this way. But what farmers and gardeners are thoroughly alive to, is the necessity of taking steps to increase the percentage of humus, that is to say, decomposing vegetable material, as represented by farmyard manure, decomposing turf, leaf

mould, green manure, and the like. Such material, by binding together the particles of sand, does much to diminish the excessively non-cohesive condition of sandy soil.

In the case of strong clay, which is too cohesive, much may be done to produce a more crumbly consistency by early ploughing, and the exposure of the rough furrow to the action of winter frost and spring sun. Even the most plastic clay crumbles down in the course of the winter; and in spring, if the conditions are sufficiently dry, it may be almost mealy in character. The alternations of temperature during winter and spring, the disintegrating action of frost, the corroding effects of the oxygen and carbonic acid of the atmosphere, and other natural agents, have been at work, mellowing the soil, and producing what every farmer likes to find in abundance in spring, a good tilth. But this desirable condition of the soil can be very easily destroyed by injudicious treatment, and every experienced farmer and gardener knows that the most beautifully tilthy soil may be converted into a plastic, sticky mass, too cohesive when wet and too hard when dry, if strong land is worked when out of condition. It is in spring that one must be most careful, at a time, namely, when the

chances of a spell of corrective frost are past ; mistakes in autumn are of less account, and the less so the more severe the winter that follows. In the case of clay, as in the case of sand, the addition of humus does much to improve its character in the way of cohesiveness ; for whereas this substance increases the cohesiveness of sand it has the opposite effect on clay, making it more easily broken down and brought into a desirable mechanical condition.

Then, again, not only must the particles of soil possess the property, within limits, of sticking together, but they must also have the power of retaining water. Soil may be practically sterile either because it contains too little water or because it contains too much, the proper degree of moisture as a rule being reached when the soil feels damp to the hand. It is on the water that is held between the soil particles that plants feed, and through which agency they derive all the mineral material which is vital to their existence. In the case of sand, the capacity of the soil to retain water is increased by the addition of humus, whose power of absorbing water is much greater than that of sand itself. Clay also is improved by the addition of humus, which, to some extent, loosens the

soil and facilitates the entrance of air. Its presence, also, tends to diminish the resistance offered by the soil to the extension of the root range of plants, and to the upward growth of young seedlings.

Intimately associated with the capacity to retain water is the power that soil, in common with many substances, has to raise water from deeper layers, and to attract it horizontally from one point to another. Did the soil not possess the power of bringing water from the subsoil to the region where plants dispose their roots, our farm and garden crops would seldom be able to survive an ordinary summer. Experiments have shown that many crops in the course of a growing season part with much more water to the air than directly reaches the land during that period in the form of rain, and it is only by tapping underground supplies through the agency of capillarity, that crops are able to grow during weeks and even months of persistent drought. The power possessed by soil of raising water against the force of gravity can be illustrated by taking a lump of dry clay and dipping the lower part into a bowl of water, when it will be seen that a certain amount of the water instantly rises into the clay, which, if held long enough in contact

with the water, will be found to become entirely saturated. In respect of this property soils vary greatly. Some can raise water rapidly but not to a great height, others will raise water slowly but, given time, the water will reach a much higher level than in the other case. It has been found that the property largely depends upon the fineness of the particles of soil, or, in other words, on the size of the interstices between the particles. Nowadays it is usual to speak of the property, by the exercise of which water rises in the soil, as "surface attraction," each particle of soil covering itself with a thin film of water, which diffuses from particle to particle until the whole mass is equally moist. Coarse sand, for instance, does not raise water so effectively as sand with finer grains; clay, with its fine particles, raises water rather slowly but to a comparatively great height. Humus facilitates the rising of water and, therefore, improves the conditions of sand. Of all the soils with which a farmer has usually to do, fairly pure sands are most likely to suffer from the effects of drought in a season when rain is deficient. Much, however, can be done to improve matters by increasing the supply of humus, so that a sand, comparatively barren in its

natural condition, may become most useful for cultural purposes if steps are taken to increase the stock of decomposing vegetable matter in it.

As the outcome of experience, methods of cultivation have been adopted whereby this property of soil is utilized to the fullest extent. When seed is deposited in a field or garden, and is covered with an inch, more or less, of soil, it is desirable that it shall without loss of time be sufficiently supplied with water, so that no delay shall occur in germination. By rolling land after the seed is sowed, or by compressing a seed-bed with the back of a spade, the cultivator brings the particles of soil on and near the surface of the ground closer together, and thus, by diminishing the interstices in the soil, increases the property of capillarity. As a result, water rises from the subsoil right up to the surface of the ground, and in its passage comes into contact with the seed, which by absorbing moisture undergoes the changes which collectively result in what is called germination. It is true that by inducing the water to mount to the surface of the ground a certain proportion escapes into the air and is lost to the crop, but such loss is inseparable from the advantages that are gained in pro-

viding the seed with the water that it requires. When the seed has germinated, and has pushed its roots some inches into the soil, the necessity no longer exists of inducing water to rise to the point in the soil where the seeds had been placed, and it now becomes more desirable to conserve water in the subsoil than to encourage it to rise to the surface. The plant by means of its roots can now draw water from comparatively deep layers, and what farmers and gardeners generally do at this stage is to hand-hoe or horse-hoe the surface of the ground, whereby the interstices in the soil are increased in size. In this way the power of capillarity is diminished, and water is prevented from rising to the surface and escaping into the air. A loose covering of well-disintegrated soil is called a soil-mulch, and such a covering will prevent the upward escape of water in much the same way that a mulch of rough manure laid upon, for instance, a rose-bed, will conserve water for the use of plants growing there.

The utilization and conservation of rain-water and melted snow, through the agency of cultural methods, has received much attention during the past few years in most of the drier regions of the world. In certain

areas of Canada and the United States, for instance, the annual rainfall does not exceed 10 inches, a quantity quite insufficient to meet the requirements of such a crop as wheat. In these districts it is now a common practice to crop the land only once in two years, the intervening year being utilized for the purpose of collecting and storing water in the soil for the use of the crop during the succeeding year. During the year of bare fallow the field is frequently stirred to the depth of 3 or 4 inches by the cultivator and harrows, and may once or twice be shallow ploughed, the result being that the loose, dusty condition of the surface soil prevents water rising to the surface, and escaping into the air. The rains and snows of one year are thus added to the atmospheric precipitations of the next, and by this means crops can be grown in alternate years under conditions that would otherwise prevent their being grown at all.

In the drier parts of Britain much of the attention of the cultivator should be given to the conservation of soil moisture. Not only should ground not yet under a crop be lightly cultivated in spring, but during summer also, when a crop is being grown, attention should be given to careful inter-

cultivation—assuming the crop is drilled—so that as little water as possible shall be allowed to escape into the air, except through the leaves, and such water, of course, has done all the work of which it is capable. If, on the other hand, the soil is allowed to become encrusted, water rising from the sub-soil by capillarity has no difficulty in reaching the surface and is uselessly evaporated into the air. It may be that such loss of water is increased by the growth of weeds, which not only rob a crop of its food, but also deprive it of a certain proportion of the water which is vital to its existence. The importance of water-conservation has been more recognized of late years by farmers, but in this respect gardeners certainly led the way. Most gardeners know that the requirements of plants for moisture are almost as well met by the use of the hoe as by the use of the watering-can, in fact in some cases it may be said that the hoe supplies water more satisfactorily than the watering-can, because whereas water falling from a can consolidates the surface, water rising from below produces no such undesirable results.

We are apt to associate surface attraction or capillarity with the vertical movement of water, but the same force is equally operative

in a horizontal direction, should the soil at any point become drier than adjacent soil on the same level. When, for instance, a plant is feeding, that is to say, when it is taking in mineral food dissolved in water, its root hairs are draining the soil of moisture in their immediate neighbourhood. Had the soil no power to bring fresh supplies of water into contact with the root hairs, the latter must cease to feed directly they have abstracted the moisture from the soil in their immediate vicinity. But no sooner is the moisture withdrawn from such soil than equilibrium is upset, and from all directions—from below, from the side, from above—the small mass of soil, which has been drained in the way indicated, has the power of attracting water, so that there is a constant movement of moisture towards the tips of the roots, namely, the parts of the plant where water is most required. This water carries with it the potash, phosphates, nitrates, and other plant food required by the crop, and although the solution is a very weak one the aggregate amount of mineral matter and nitrates that passes into an average crop in a growing season may amount to several hundred pounds per acre. It is this food that nourishes the cells of the

plant, and thus helps those of the leaves in their characteristic work of decomposing the carbonic acid gas of the air, which enters into the leaf, chiefly through the minute apertures (*stomata*) so abundant on the surface of leaves, and also, though to a less extent, on young shoots. It is from the carbonic acid gas of the air that plants get their carbon, a substance that constitutes about one-half of the dry matter of a crop, all of which has been abstracted from the atmosphere with which the leaves and stems are bathed. The mineral matter may not exceed five per cent. of the dry weight of a crop, and yet it is just as essential to growth as the carbon which is so much more abundant. Mineral matter is all absorbed from solutions in the soil, not entering through any definite apertures in the roots or root hairs, but passing through the bounding membrane of the root hairs, which themselves are lateral outgrowths of epidermal cells. There would be no movement of water and plant food from the soil into the roots were it not for the fact that the solutions (cell sap) in the root hairs and epidermal cells—for some plants have no root hairs—are stronger than the solutions in the soil. But, given these conditions—namely,

a comparatively strong solution of sugars, etc., in the epidermal cells and root hairs, and a very weak solution of mineral matter in the adjacent soil—the water carrying the mineral food has the power of passing through the membrane and so of getting inside the plant. Having gained an entrance it moves upwards, owing to the fact that water is constantly being expired from the upper part of the plant; and in some way, not yet altogether satisfactorily explained, the water, with what is dissolved in it, moves upwards to replace that which is withdrawn. During the growing season, there is a constantly ascending stream which has its origin in the soil and its destination in the atmosphere. The mineral matter present in this ascending stream is not expired into the air, but is retained by the plant and utilized for its vital requirements. Experiments have shown that for every pound of dry material—mineral and organic—stored up in the plant some hundreds of pounds of water have passed through the plant tissues.

The passage of water through a membrane, and its diffusion throughout a solution inside, can be demonstrated in various ways.] If, for instance, we take a hollow glass cylinder, 6 inches or so in length, and

open at both ends, and place a piece of bladder across one end, subsequently filling it with a strong solution of sugar, and then close the other end with a similar membrane, we shall find that if the cylinder be placed in a basin of water the membranes will be pushed outwards owing to internal pressure set up in consequence of the movement of water into the cylinder. Or, conversely, we may have the solution of sugar in the basin, and water in the cylinder, when the membrane will be pushed inwards owing to water having passed the membrane and intermixed with the sugary solution in the basin. Cells which are subjected to internal pressure, and whose membrane is stretched, are said to be "turgid"; whereas cells with no internal pressure are said to be in a condition of plasmolysis. The growing shoot of a herbaceous plant, for instance, has its cells in the turgid condition and, consequently, stands erect; but if such a shoot be severed from the plant it speedily becomes limp and droops, because when water can no longer move up the stem to maintain internal pressure in the cells the latter rapidly pass into the condition of plasmolysis.

While the requirements of plants as regards water are, to the greatest extent, met by

the supplies provided directly or indirectly by rain or melted snow, it may be mentioned that soil, in common with many other substances, has the power of condensing a certain amount of water from the vapour naturally present in the atmosphere, and such water is not without influence in the soil. This property of soil may be demonstrated by thoroughly drying a small quantity in an oven and then leaving it exposed in a room. If the weight of the soil be accurately determined immediately after drying, and again after exposing to the air for two or three hours, it will be found that the soil has undergone considerable increase in weight, and it is not difficult to prove that this increase is due to the condensation of moisture from the atmosphere. Certain of the constituents of soil, notably humus, have this power to a greater extent than others; while some artificial manures, *e.g.* kainit and nitrate of lime, act in a similar manner, and to an even greater extent; but it is doubtful whether artificial fertilizers are ever applied in such quantity as to have any appreciable influence upon the total water contents of the soil.

The soil has not only interesting and useful relationships with water, but certain of its properties as regards heat are also of

vital importance to the life of plants, and to the profitable cultivation of crops. If certain definite weights of such substances as iron, copper, and lead, are exposed to the same amount of heat for definite periods it will be found that the temperature of these bodies varies considerably, showing either that they have taken up varying quantities of heat or that for the same amount of heat their temperature has responded in varying degree. The property of a body to absorb heat is known as its capacity for heat, the standard of measurement being the capacity for heat, or the Specific Heat, of water. Specific heat may be defined as the quantity of heat which a definite weight of a substance requires in order that its temperature may rise through one degree of temperature, that of water being taken as unity. The important constituents of the soil show marked variations as regards their capacity for heat, and, according to the proportion in which the constituents are present, soils may be warm or cold. Of all the constituents of soil, water is the one which requires most heat in order that its temperature may rise through a definite number of degrees ; that is to say, it stands at the top of the list as regards specific heat. The specific heat of water

being represented by 1,—that is to say, being taken as unity,—that of the other constituents of the soil will be represented by a fraction of 1. Thus the specific heat of humus is about 0·5, the specific heat of carbonate of lime and clay about 0·25, while the specific heat of sand is no more than 0·2. This means that, whereas 1 lb. of water would rise in temperature 1° when exposed to a certain amount of heat, 2 lb. of humus, 4 lb. of clay or carbonate of lime, and 5 lb. of sand would rise to the same temperature when exposed to the same amount of heat. In other words, substances of low specific heat, like sand, are readily warmed when exposed to the rays of the sun, whereas a soil containing much humus is not so easily heated, and a soil that holds a large quantity of water remains coolest of all. Wet soils, therefore, are cold soils, while sandy soils are warm, so that it is evident that the specific heat of soil must have a marked influence on the rapidity of germination of seed, as well as on the growth of plants, and the time of harvest. Within limits it is an advantage that a soil should be warm, but in the case of such a soil as sand the temperature may rise to too high a point, with the result that crops may ripen prematurely, and

the yield may be deficient. It is, therefore, desirable to take steps to raise the specific heat of such a substance as sand, and this can be done by adding to the stock of humus that it contains; for not only does humus in itself keep sand cool, but, being a powerful absorbent of water, it enables the soil to hold more water, and nothing depresses the temperature so much as this substance.

The temperature of a soil depends not only on its specific heat, but also upon its power to absorb or reflect heat, and this property is influenced to a considerable extent by its colour. Other things being equal, a white or light-coloured soil is a cool soil, because the sun's rays are not so readily absorbed by a white surface as by a dark. If, for instance, two vessels are filled with soil, the surface of which, in the one case, is whitened by a dusting of lime, while, in the other, it is blackened with a sprinkling of soot, it will be found, after exposure to sunlight, that the temperature of the soil with the dark surface is higher than the temperature of the same soil which has been sprinkled with lime. This property of soil and other bodies, whereby their temperature is influenced by their colour, is illustrated in practical life by the fact that human beings

wear lighter-coloured garments in summer than in winter, the intention being to reflect the sun's rays in summer and to absorb them in winter. It may often be noticed, also, that in warm districts the roofs of houses are painted white in summer, the white colour throwing back or reflecting the sun's rays, many of which would be absorbed if the roof were black or any other colour but white.

The great and immediate source of heat, so far as soil is concerned, is the sun; but the temperature of soil is, to some extent, influenced by heat directly received from other sources, such as decomposing vegetable matter. Every one is familiar with the fact that a mass of farmyard manure—especially easily-fermentable material like horse manure—has a comparatively high temperature, and this source of heat is utilized in gardening practice in the propagation of plants in frames. If the same amount of manure were spread over a considerable area of ground, one might be disposed to think that it was providing no heat; but, in point of fact, the amount of heat given out during its decomposition by, say, 10 tons of farmyard manure is precisely the same, no matter whether it is concentrated below a garden

frame or is spread over an acre of land. Probably the heat liberated in the soil by the decomposition of such a moderate dressing of manure as 10 tons per acre would be difficult to detect by means of an ordinary thermometer, but if the dressing of manure were 50 tons or more per acre—as is not uncommon in intensive horticultural and agricultural practice—the influence on the temperature of the soil would be quite appreciable. The decomposing remains of a former crop, as represented by plant roots, stubble, etc., also give out heat, although not so rapidly as more easily decomposable farmyard manure; but still, as a source of heat, they have to be taken into account in considering the various factors affecting temperature. The production of heat in this way is a consequence of oxidation, that is to say, it is due to the union of the oxygen of the air with some substance which either contains no oxygen, or contains less oxygen than it is capable of combining with.

Although vegetable matter oxidizes more rapidly than other substances in the soil, it may be mentioned that low oxides of iron and other elements can take up more oxygen, and, in the process of combining, heat is liberated to affect bodies in its neighbourhood.

Then, again, it must not be forgotten that there is an enormous amount of heat in the centre of the earth, proof of which is furnished by hot springs, and active volcanoes, and also by the fact that as one goes down the shaft of a mine the temperature rises steadily and fairly rapidly. On account of the earth's crust being a very bad conductor, the heat present in the centre of the earth is conducted outwards very slowly, but that the internal supply of heat in the earth has to be reckoned with cannot be doubted.

One of the most important properties of soil is concerned with its power of retaining, absorbing, or fixing plant food from solutions. This property is something entirely different from the power which soil, in common with many other substances, possesses of mechanically filtering out materials held in suspension in water. When a substance is in solution it is quite inseparable by mechanical processes of filtration, but it is known that soil possesses the power of removing certain of these substances and of retaining them in its mass. If, for instance, one were to fill with soil a series of glass tubes open at each end, having previously closed one end with wire gauze or muslin, and if certain

solutions of chemical substances that serve as plant food were subsequently poured on the top of the soil in these tubes, it would be found that in some cases the solutions that drained away from the bottom of the cylinders were weaker than the solutions that had been poured in on the top. Clearly, therefore, the soil had, in some way or other, abstracted material from the solutions. In other cases it would be found that the solutions draining away from the foot of the tubes were of as great strength as those which were poured in above. It is evident that substances which are absorbed by the soil are in least danger of being lost in drainage waters, while those that are not so absorbed have more chance of escaping, and of being lost so far as crops are concerned. The three most important elements of plant food that are supplied in artificial manures behave somewhat differently as regards this property of soil. Potash and phosphoric acid, even in a soluble form, when applied in moderate quantities, are not in danger of being lost to any appreciable extent. The danger, therefore, of loss through heavy rainfall is not great in the case of these substances. As regards nitrogen, it is found that when this is applied in the form of ammonia, *e.g.* sulphate

of ammonia, it is fairly well fixed by the soil, whereas when the nitrogen is in the form of nitric acid, *e.g.* nitrate of soda, the soil has practically no power to remove it from solutions. Lime, magnesia, and soda are also but little removed from solutions, and therefore these substances, in common with nitrates, bulk comparatively largely in the drainage water of our fields.

In connection with this subject it may be mentioned that the soil absorbs relatively most from weak solutions, while its power of absorption is reduced almost in proportion to the strength of the solution. If, for instance, a solution containing one-twentieth per cent. of sulphate of potash is poured through soil, about one-half may be removed; but if the solution is twenty times as strong, that is to say, if the solution is of the strength of one per cent., the percentage of potash absorbed will only be about one-third of the relative quantity removed in the other case. There is therefore greater danger of loss by drainage where one applies a very heavy manurial dressing than where one is giving only moderate doses.

The causes of such removal of substances from solution are rather various, but in the case of mineral substances the agents that

affect the fixation are the lime, iron, and similar bases that are naturally present in abundance in all soils. In the case of ammonia it is probable that the most important fixing agent is humus, which, as is well known, has great power of mechanically storing up ammonia in its tissues. We have a good example of the affinity of humus for ammonia in the fact that where moss litter—which is a form of humus—is used in stables the atmosphere is much less redolent of ammonia than where the litter is straw.

As regards soils, it is found that the least power of absorption is possessed by sand, while the property is most conspicuous in strong loams, clay, and soils that contain much decomposing vegetable matter.

CHAPTER III

THE MAIN TYPES OF SOIL

WHILE soil is in many respects a very complex substance it can, from the agricultural point of view, be regarded as composed mainly of four substances, that is to say, in all soils one or other of these four

materials constitutes the bulk of the mass. In some soils the main ingredient is sand or quartz, in others it is clay, in some it is carbonate of lime, while in soils of the fourth class the predominating material is humus.

Soils whose main constituent is sand or quartz grains has definite and easily recognizable properties. In the first place it undergoes little if any further change under the processes of weather, for the reason that the siliceous material which forms the bulk of its mass is not decomposable by the action of natural agents. It is said to be light, in the sense that the labour of working it is easy. It is generally dry, because its mechanical condition permits of the easy drainage of water. It is warm, partly because it has a low specific heat, and its temperature therefore rises quickly under the influence of sun or warm air, and partly because it holds little water, and therefore this substance of high specific heat is not present to keep it cool. Not only does water, in consequence of its high specific heat, prevent the temperature of soil from rising, but it also tends to make soil cool, owing to the fact that where one has water one has always more or less evaporation, and the conversion of water from the liquid into the gaseous

condition is always accompanied by the disappearance, in an easily perceptible form, of heat. This result can be readily illustrated in a variety of ways. If, for instance, we moisten the back of the hand and then blow upon the moistened surface, so as to cause rapid evaporation, we notice that the skin is manifestly cooled to a greater extent than would be the case were the moisture allowed to evaporate more slowly. A flask containing liquid can be kept cool in hot weather by surrounding it with some absorptive material like flannel, and if this be saturated with water, the latter will evaporate when freely exposed to the air, and the withdrawal of heat from the liquid in the flask will be indicated by a fall in temperature.

During dry weather, when water is removed from sand by evaporation or otherwise, the soil does not shrink to any great extent, and, consequently, sandy soils never show cracks during periods of drought. Owing to the comparatively small amount of water that sand can take up and retain, and also because of the ease with which it parts with moisture, crops are apt to ripen prematurely on such soil and are always deficient in yield during seasons of low rainfall. Other things being equal, therefore, sandy soils give their best

return in a district of heavy rainfall ; in fact in districts where the rainfall is low, sands may be practically barren. On the other hand, no soil is so suitable for purposes of irrigation, no matter whether the water that is used is comparatively pure, or whether it is of the nature of sewage. To get the best returns from irrigation the water must filter through the body of the soil, and escape into the drains or the sub-soil. In this way the water is brought more directly into contact with the roots of plants, and the substances held in suspension are more completely separated and retained in the body of the soil.

Sandy soil, although poor in itself, is well fitted for intensive agriculture or, as it is otherwise called, high farming. But a first necessity in adapting soil for intensive agriculture is the provision of an abundant supply of humus, and this is usually most easily secured by liberal dressings of farmyard manure. Another way of adding to the stock of decomposing vegetable matter in soil is through the agency of green manure, that is to say, by the growth of a quick-growing crop, capable in a short time of forming a large quantity of herbaceous material, which can be dug or ploughed into the soil, and

thus add materially to the supply of humus. The crop which in this country is most usually cultivated for this purpose is white mustard, which within six weeks or two months of being sowed may have grown to a height of a foot or more, producing excellent results when incorporated with the soil. Other crops that are used for a like purpose are rape, and certain leguminous plants, such as lupins, serradella, and clover. Other things being equal, it is better to use a leguminous plant for this purpose, because, as is well known, such plants not only add organic matter to the soil, but they also increase the stock of nitrogen through the power that they are known to possess of fixing this material from the supply present in limitless quantity in the atmosphere. But the seeds of leguminous plants are more costly than those of mustard, and, moreover, their cultivation demands a longer period of growth, and is more dependent upon suitable conditions of soil and weather.

Although theoretically one should select a leguminous crop for the supply of humus, experiments on green manuring conducted by the Royal Agricultural Society of England on sandy soil at Woburn, in Bedfordshire, show that better crops are often got after

mustard and rape than after preliminary treatment with vetches. This rather unexpected result is probably to be explained by the fact that decomposing mustard or rape has greater power of absorbing and retaining moisture than vetches, and as moisture is quite as important as nitrogen in the growth of crops, the former has proved to be the more powerful determining factor at this particular station. It may be, also, that rape and mustard bring the soil into superior physical condition.

While green-manuring is doubtless sometimes justifiable, it pays better, as a rule, to consume crops by stock than to cultivate them exclusively for fertilizing purposes. Thus, in the case of crimson clover, it will usually be more profitable to feed off the crop with sheep, and to depend for an increase of humus on the roots that are left in the soil, and on the excreta dropped on the surface by the animals. Of course, a considerable proportion of the organic matter is dissipated by the consumption of the crop by animals, and therefore the amount of humus added to the soil is correspondingly reduced ; but the advantages to the live stock, as a rule, outweigh the disadvantages of reducing the available supply of humus, and, consequently,

green manuring, as a practical agricultural operation, is, on the whole, not common.

The stock of humus in soil is also increased, often to a large extent, by laying down land to grass, either for a number of years or permanently. The turf that forms is entirely composed of vegetable matter, and should such land again be broken up, the stock of humus will be found to have materially increased.

Many of the more important market-gardening districts of England are situated upon sandy soil, and no system of agriculture is more intensive than market gardening. One of the best known market-gardening centres in England is on the Lower Greensand in the neighbourhood of Biggleswade, Pottton, and Sandy, in the county of Bedford. There it is not unusual for three crops to be taken off the same area of ground in a single season, and such a result is only possible where land can be worked under practically all conditions of weather, so that no delay is experienced between the removal of one crop and the sowing or planting of its successor. Directly rain ceases to fall one may proceed to plough, cultivate, or sow sandy land, whereas, in the case of clays a considerable interval must elapse after rain before one can venture to tread the soil, or to work it by means of

hand or horse implements. Such delay, which may extend over days if not weeks, is quite fatal to success in market gardening or any intensive form of cultivation. As a consequence one seldom finds clay utilized for anything but the growth of what one may call standard farm crops, cultivated on the conventional system.

Sandy soils are not only light, dry, and warm, but they are also markedly non-absorptive in respect of soluble plant food, so that there is greater danger of loss of such material from sands than from any other soil. Other things being equal, therefore, one would use sulphate of ammonia rather than nitrate of soda, so that any little power of absorbing nitrogen that sandy soil may possess will have an opportunity of exerting itself. It is seldom prudent to apply very heavy dressings of artificial manures at long intervals, but in the case of sandy land it is specially desirable that manurial substances should be put on in comparatively small doses and at short intervals. Sandy soil, especially if it holds a fair amount of lime, is well adapted for the use of manures that require to be decomposed before serving as the food of plants. Such substances as bone meal, dissolved bones, fish manure, and rape meal,

contain only organic nitrogen, that is to say, nitrogen in a form in which it can directly be utilized by animals, but not immediately by farm crops. Such substances require to decay, and to have their organic nitrogen converted into some other form, before higher plants can make use of them, and this change is intimately associated with abundant supplies of air, and no soil contains more air than sand. Then, again, the process of conversion is facilitated by heat, and in this respect sandy soil offers more favourable conditions than clay. The result is that the class of manures referred to is specially adapted for use on sandy land, and, conversely, is ill-adapted for use on clay. That sandy land offers conditions favourable to decay, is well illustrated in the behaviour of fencing posts, which, in light soil, decompose very rapidly, and probably require renewal within a few years of the erection of the fence; whereas the same class of post inserted in clay soil may have a "life" three or four times as long, and come out of the ground comparatively sound after twenty or thirty years.

The characters of clay are, to a large extent, the opposite of those that are associated with sand. Clay in itself has a much more complex composition, and although

when pure it contains nothing of value as plant food, it always holds considerable quantities of substances passing into the form of clay, which contain materials like potash that can be utilized in the nutrition of plants. Just as sand may be defined chemically as oxide of silicon, so clay may be defined as a hydrated silicate of aluminium. Bodies are said to be hydrated when they contain water as an essential part of their composition, and so long as clay is hydrated it is plastic and sticky, and can be moulded into any desired form. But the water of hydration can be driven from clay by exposure to a somewhat high temperature, and then the substance is no longer clay. Although it is still a silicate of aluminium, it is not a hydrated silicate. This change takes place where clay is burned in the process of brickmaking, the main difference between a brick and clay being that the former does not contain water as an essential part of its composition, whereas the latter does.

When clay has been dehydrated it cannot be restored to its original condition by any ordinary process, so that one may grind a brick into powder and mix it with water, but one will not by so doing restore the characters of clay. The same change is

effected when clay is dried in the sun and piled in heaps mixed with combustible material, which is subsequently fired and the whole mass roasted. This is an agricultural process, called clay burning, which at one time was commonly practised upon the strong lands of England. During the process of roasting, a certain amount of mineral plant food was liberated, and when the burned material was scattered upon the fields this plant food became available for the use of crops. But the main object of burning clay and spreading it on land at the rate of 50 to 100 tons per acre was to provide material which would modify the plastic character of the clay, and, by imparting greater friability, facilitate tillage operations.

For most agricultural purposes the soil that gives the best return is a loam, which consists of an intimate admixture of clay and sand in varying proportions. According as one or other of these substances predominates we have a clay loam or a sandy loam. In its physical properties a loam stands more or less intermediate between a sand and a clay. While manurial substances are more liable to loss on a loam than on a clay, their action is more rapid; and, on the whole, loams admit of manures of all kinds being very fully utilized.

The third substance that enters into the composition of all soils, and constitutes the major part of many, is lime, which may be present in the form of a simple carbonate, as in the case of Chalk, or a double carbonate of lime and magnesia, as in the case of Dolomite, a type of soil which is common on the Magnesian Limestone formation in the north-east of England. Lime is also present as a component part of certain silicates, but when in this form it is not so readily available for the uses of plants. In the Chalk districts of England, where, on steep slopes and escarpments, the rock comes close to the surface, the soil may contain seventy per cent. and upwards of carbonate of lime. At the bottom of the slopes, and on the tops of the hills, where the ground is more level, the depth of soil is generally much greater, and one may have to dig down some feet before coming on chalk. Under these circumstances the soil contains much less lime, in fact, on the top of the Chalk Downs there may be as little as one per cent. of lime in the surface soil, although at the depth of only a foot or two the soil may consist almost entirely of this substance. Lime, in fact, is a substance that is comparatively soluble in water, and especially in water that is charged with

carbonic acid gas, and for this reason, and also because it is not much "absorbed" by soil, it is rather easily washed out, and so removed from the feeding range of plant roots. The ease with which lime may be removed from soil is well illustrated by the experiments at Woburn and Rothamsted. At both these stations sulphate of ammonia has been used for many years on the same plots, with the result that practically all the available lime has been washed out of the land. It would appear that the sulphuric acid of the sulphate of ammonia has combined with the lime of the calcium carbonate to form gypsum, and in this form the lime has disappeared in the drains, or has been removed to the subsoil beyond the reach of plants. This is a danger that has to be borne in mind where sulphate of ammonia is used liberally at short intervals.

Soil containing much carbonate of lime possesses very definite properties. It fixes energetically soluble compounds of phosphoric acid, such as are present in superphosphate of lime and dissolved bones. But its power of fixing most other substances is rather limited. As a rule such a soil contains but little potash, nor does it generally show a high percentage of nitrogen.

Fertilizers, such as farmyard manure, bones, rape meal, etc., which supply organic nitrogen, undergo rapid decomposition in calcareous soils, the nitrogen being converted into nitrates, which, unless appropriated by plants, quickly sink down into the soil, and are removed in the drainage water. Other things being equal, such a soil is probably better suited to the use of sulphate of ammonia than of nitrate of soda. But, whatever form of nitrogen be used, dressings for a calcareous soil should be moderate and frequent, rather than large and at long intervals.

The fourth substance which is always present in soil, and which may on occasion form a large proportion of the whole, is humus. This is a substance of indefinite composition which has its origin in the decay of vegetable matter. According to the stage of decomposition, so does the composition of the humus vary, and its character also depends to some extent upon the kind of plant remains of which it is composed. In all cases, however, it contains carbon, hydrogen, oxygen, nitrogen, and the mineral matter which the plants forming it took up and stored in their tissues during growth. Humus, therefore, is capable of supplying crops with mineral plant food, such as

potash and phosphates, while it also serves as a source of nitrogen. But the nitrogen present in humus is in the organic form, and therefore cannot be utilized by the higher plants until it has been converted into nitric acid. The first stage in the process of conversion is the formation of ammonia, and this is attacked by minute living organisms and worked up into nitrous acid, which, combining with a base such as lime, forms the kind of salt called a nitrite. This combination of nitrogen, however, is not immediately important as a plant food, but it is seized upon by another set of organisms, by which it is induced to combine with more oxygen. Thus highly oxidized, it becomes nitric acid, which similarly unites with a base (generally lime) to be converted into a nitrate, a salt which plants can immediately utilize as food. This process, which goes by the name of nitrification, is dependent upon certain definite conditions. In the first place, a nitrifiable substance must be available, and the organisms necessary to convert the nitrogen into nitric acid must also be present. These minute bodies (bacteria), like all living organisms, demand certain conditions in order that they may work satisfactorily. A supply of oxygen in the soil is essential to

their activity, and, as a consequence, nitrification goes on more energetically in a soil that is well aerated than in one which is less supplied with atmospheric oxygen. Nitrification therefore takes place to a greater extent in the surface soil than in the sub-soil, in a sandy soil than in a clay soil, and in a soil which is frequently stirred by agricultural implements than in one which is allowed to become dense and encrusted. Also, like most other living things, the nitrifying organisms can only work well when the temperature is satisfactory. Their activity ceases entirely when the temperature approaches the freezing point, and, similarly, they are put out of action by a temperature that rises above 130° F. It is found by experiment that the temperature which suits them best is in the neighbourhood of 100° F. On account of their dependence upon a comparatively high soil temperature, the nitrifying organisms are practically inactive during winter, performing most of their work during summer and autumn. Crops, therefore, like wheat, which are sowed in autumn, and make a large part of their growth during winter and spring, are often well supplied with available nitrogen, and especially so if they follow a well-worked bare-fallow. The

character of the weather in autumn and winter has, however, much influence on the supply of nitrates; if the rainfall is heavy they are largely washed out of the land, whereas if the season is dry they are more likely to be utilized by winter crops. So intimate is the relationship between the rainfall of the last quarter of the year, and the supply of nitrates, that by a study of the rainfall-figures it is possible to make a fairly accurate forecast of the yield of the succeeding wheat crop. If, on the other hand, winter wheat should not have been well supplied with natural nitrates, it will be found to respond readily to spring dressings of nitrate of soda. Other crops, like turnips, which are not sowed until summer, make their growth at a time of the year when the conditions of nitrification are at their best. As a consequence such crops are well provided with nitrogen, which has been converted into an available form during their period of growth, and they are therefore not so dependent on supplies of artificial nitrogen as a crop that makes its growth at a season of the year when temperatures are lower. While there is no doubt that turnips respond in many cases to artificial dressings of nitrate of soda or sulphate of ammonia, the quantity

required, and the result produced, are much less than in the case of cereals.

Another essential condition of nitrification is a sufficient supply of moisture, but if water in the soil is so abundant as materially to reduce the supplies of air, or to keep the soil cold, it may have a retarding rather than a stimulating influence upon the process of nitrification.

Lastly, the conversion of organic or ammoniacal nitrogen into nitric acid, and finally into a nitrate, is dependent upon the presence of a base with which the nitric acid may combine as soon as it has been formed. Nitric acid, as is well known to those who have had any laboratory experience, is a highly corrosive substance, which, if accumulating in quantity in the soil, would immediately react upon the organisms producing it, and put them out of action. There is a law, applicable both to physical and biological problems, that may be expressed by saying that the accumulation of the products of an action tends to put a stop to that action. If, for instance, the product of the action of nitrification, namely nitric acid, be allowed to accumulate in the soil it will quickly interfere with the activity of the organisms, and compel them to cease working.

Nitric acid, however, can be rendered innocuous to the nitrifying organisms by giving it access to a base with which it may unite to form a neutral salt. Whereas nitric acid in its free state is highly corrosive, it becomes perfectly innocuous when it is brought into contact with such substances as lime, potash, or magnesia, with which it enters into chemical combination to form nitrates of lime, potash, and magnesia respectively, substances which have no prejudicial effect upon living organisms with which they may be brought into contact. Nitrate of soda, a manure that is largely sown by hand, is an example of a combination of nitric acid and a base that has no injurious effect on animal tissues. The base with which nitric acid most frequently unites in the soil is lime, and it is the stimulus given to nitrification that chiefly accounts for the marked effects of this substance when applied to land rich in humus.

Not only do organisms form nitrates out of plant and animal remains, but another set of organisms can attack nitrates and reduce them to free nitrogen, which escapes into the air and is lost to crops. This process of denitrification, as it is called, takes place in the absence of a sufficient supply of air,

and is most likely to occur, therefore, in the subsoil, or in soil saturated with water.

Important as are the biological and physiological aspects of humus, its physical effects upon the soil are no less important. It is not too much to say that no soil can be quite satisfactory for agricultural or horticultural purposes that does not contain a considerable proportion of humus. Its effects on sand are to make it more binding, to add to its absorptive properties for soluble plant food, to render it more capable of taking up and retaining water, and to prevent its becoming overheated in bright sunshine, and chilled during the night. When added to clay, humus improves drainage, facilitates the entrance of plant roots, diminishes the tendency for the surface to become encrusted, and in its decomposition sets free carbonic acid gas, which attacks such substances as potash compounds, and in this way liberates mineral food for the use of plants. While, however, a reasonable amount of humus, say up to ten per cent., is entirely beneficial, excess may produce undesirable results, as is seen in a pronounced form in the case of peaty land, which is often sour, and incapable of growing satisfactorily the better class of plants.

Although the two subjects are not really connected, one's mind naturally turns, on thinking of nitrification, to the peculiar relationship of leguminous plants to the free nitrogen of the air. It is many years since observers suspected that the nutrition of leguminous plants differed in some respect from that of plants belonging to other natural orders, but it was only some thirty years ago that exact experiment proved that this class of plant could utilize for their nutrition the free nitrogen of the atmosphere. As is well known, the atmosphere contains some seventy-nine per cent. of uncombined nitrogen, and it is sometimes said that the main function of this nitrogen is to act as a diluent of the oxygen which constitutes the bulk of the remainder of the atmosphere. For most plants and all animals, so far as we know, this atmospheric nitrogen is of no direct account, but an exception to this rule is furnished by the Leguminosæ, and a few other less-important orders, which, through the agency of colonies of bacteria that establish themselves in outgrowths (nodules) on the roots, are able to draw upon the supplies of free atmospheric nitrogen. In some way or another, these organisms can evidently lay hold of, and

work up into organic compounds, this free nitrogen, and afterwards hand it on to the plants on which the colonies have established themselves. This association of two organisms for the mutual benefit of both is not uncommon both amongst plants and animals. In the case we are considering the leguminous plant offers, as it were, house-room to the bacteria, which, in return for the accommodation thus provided, convert the free nitrogen into such a form that it can be appropriated by the higher plant.

Without these colonies of bacteria the Leguminosæ are practically as helpless with regard to nitrogen as any other plants. It has been asserted that it is a matter of chance whether any particular leguminous plant shall come into contact in the soil with its appropriate organism, and it has been suggested that fields intended for the growth of a leguminous crop should be "inoculated" with a culture of the organism which can best enter into association with the particular crop that it is intended to grow. Various so-called cultures have from time to time, during the past ten to fifteen years, been put upon the market, and farmers and gardeners have been led to expect great results from their use. But in

practice, or when investigated scientifically by unprejudiced inquirers, such cultures have proved to be of little, if any, account, and at the moment one hears but little of them. While it is certain that leguminous plants cannot attract colonies of bacteria to their roots unless the bacteria are present in the soil, it would appear that practically all soils contain the necessary organisms in abundance, and that the addition of further supplies is unnecessary. It has also been alleged that each leguminous plant can only associate itself with its own particular organism, or with one that is very closely allied. It is maintained, for instance, that nearly-related leguminous plants, such as white and alsyke clovers, are capable of attracting the same variety of organism, whereas species standing wide apart, like beans and medick, have no mutual interest in any particular organism. But common observation will furnish evidence that this cannot always be the case. In the Weald of Surrey, for example, it is the rarest thing to find broom or lucern, and we should therefore be asked to assume that the organisms on the roots of these plants cannot naturally be present in such soils, so that, should an attempt be made to cultivate these plants, successful growth is

not to be looked for. But if the seed of broom or lucern be sowed in the Weald it will be found that the resulting plants at once provide themselves with abundance of nodules, and grow vigorously. One must therefore conclude that leguminous plants generally find in the soil bacteria which are capable of entering into association with a wide range of plants, and of immediately forming colonies on species, and even genera, that they can never previously have encountered.

Beside the free nitrogen, there is a certain amount of combined nitrogen present in the atmosphere, the actual amount varying with such a circumstance as proximity to a town, where the atmosphere is more or less charged with coal smoke and other impurities. Some of this combined nitrogen (nitric acid) has been formed in the atmosphere through the agency of electrical discharges, while some (dust, ammonia, etc.) has a terrestrial origin. These substances are carried to the earth in rain and snow and so get washed into the soil, where their nitrogen becomes available as the food of plants. Very careful estimates at various places, notably Rothamsted, have been made with regard to the amount of combined nitrogen that is washed out of the

atmosphere in the course of a year, and it has been found that the quantity is not usually much, if at all, in excess of 5 lb. or 6 lb. per acre.

Besides the bacteria associated with the roots of leguminous and a few other plants, a certain number of organisms living independently in soil also possess the power of inducing free nitrogen to enter into combination, and so of becoming available for the use of the higher plants. This side of the question has not yet received so much experimental attention as the other, but enough has been done to show that such organisms are of high importance. As in the case of the nitrifying organisms, so in the case of these free nitrogen-fixing organisms, thorough aeration of the soil, and a non-acid condition, combined with a proper degree of moisture, appear to be favouring factors.

In considering the organisms that play a part in plant nutrition, one must not overlook the action of worms, which are present in practically all cultivated soils. Attention was specifically drawn to the importance of worms by Darwin, who attributed no inconsiderable part of the fertility of our fields to the action of these creatures. It is probable, however, that their effects have been considerably

over-estimated, at all events, some exceedingly poor grass land throughout the country contains worms in such abundance that at certain seasons of the year the whole surface of the ground is thickly covered by their casts. If land can remain comparatively infertile, notwithstanding a full supply of these animals, it would appear to be reasonable to assume that the fertility of good land is not largely dependent upon their work. Their action consists in opening channels in the soil, which admit air and offer a more easy means of distribution for the roots of plants. One generally finds worms, or indications of their presence, underneath stones, and by gradually removing the soil from beneath such objects, they no doubt have much to do with the fact that stones gradually sink into soil and, in the course of time, become buried altogether. Worms also help to incorporate plant-remains with the soil. At night worms come to the surface—generally, however, keeping their tails in the burrows from which they have emerged—and lay hold of leaves and other plant-remains, which they drag into the soil. In autumn and winter it will often be found that the stalks (petioles) of such leaves as ash and horse chestnut are standing

in a curiously erect position on lawns, and if examination be made it will be found that these plant-remains have been partially dragged into the burrows of worms, and so have attained to their erect position. Worms also pass large quantities of soil through their bodies, and, in the process, a certain amount of insoluble mineral matter, such as potash, is rendered more or less soluble, and therefore better fitted to serve as the food of plants. While, however, worms may contribute something to the fertility of soil, it is not to be overlooked that they also do a certain amount of harm, and especially is this the case with young seedlings, which they seize during the night, and either devour directly, or uproot and drag into their burrows.

CHAPTER IV

AMELIORATION AND IMPROVEMENT OF LAND

HAVING gained some idea of the origin and properties of soil, we are now in a position to consider processes by which land may be ameliorated or improved.

One of the oldest processes, and one which

has been practised in the past over extensive areas in the United Kingdom, is drainage, that is to say, the artificial withdrawal from soil of surplus supplies of water. While a certain amount of moisture is an essential condition of the growth of plants, and is necessary for the maintenance of many processes in the soil, too large supplies can interfere to a serious extent with the growth of crops, and of the higher plants generally. While, therefore, it is in theory desirable to get rid of surplus water, the expenses attending the operation are usually so great that in practice artificial drainage is now resorted to only to a comparatively limited extent. To drain land thoroughly, an outlay of £6 to £10 an acre is usually necessary; and when interest on this outlay, and the creation of a sinking fund for the redemption of the capital, are taken into account, it is found that the annual charges on the land are increased by something like 10s. per acre, and this is more than most land can bear with agricultural profits at their present level. It may be said generally, that tillage land which is over-wet cannot in such a condition be profitably retained under the plough, so that, if it be necessary to keep the land under tillage, drainage becomes im-

perative, even if the immediate returns from the operation cannot be depended on to cover the outlay. In the case, however, of grass land, profitable utilization is often possible, even when the land contains much more water than would justify its retention under tillage. No doubt much over-wet grass land could be considerably improved by drainage, combined with other ameliorative treatment, but it is doubtful whether in many cases the improvement effected by drainage would be such as to warrant the outlay. Without resorting to drainage it will often be found that the application of a phosphatic manure has a markedly beneficial effect, and if the land has been laid down in high, or fairly high, ridges, the surplus water will soon find its way from the field. It is often a matter for surprise how well basic slag, for instance, has acted on land which, in winter at least, is thoroughly water-logged. Sometimes one even finds the slag acting better in the furrows than on the ridges. Here, as so often happens in agriculture, results are no doubt much affected by local conditions—in other words, the character both of the water and soil is an important determining factor.

The theoretical considerations that affect

the question of drainage may be shortly set out as follows. When one constructs drains in a field that is more or less water-logged, the withdrawal of the superabundant water at once leaves vacant spaces between the soil particles, and these are immediately occupied by air which enters on the withdrawal of the water. The presence of abundant supplies of air at once creates new conditions in the soil, enabling manures to decay more rapidly and so of becoming more quickly available for the use of plants. All organic substances decay very slowly in a water-logged soil, partly owing to the low temperature of such land, but chiefly owing to the fact that under such circumstances, oxidation is much retarded. Nitrification, too, which is intimately associated with the breaking down of organic substances, is practically at a standstill.

Wet land is cold, as has previously been explained, because water, having a high specific heat, requires much heat to raise its temperature, that is to say, heat from the sun has a difficulty in making itself felt. Then again, we cannot have water in soil without a certain amount of evaporation, and whenever liquid water takes the form of vapour a great deal of heat, as the term is

popularly understood, is converted into a latent condition, to be withdrawn from the opportunity of exerting its immediate influence on soil and plants.

Land that is drained is raised in temperature, owing to the fact that rain-water, which previously could only escape by flowing over the surface, can now percolate through the soil, and such water, being often comparatively warm, tends to raise the temperature of the soil through which it passes. It has been found that water affects soil somewhat differently in summer as compared with winter, the temperature of wet land being relatively lower in summer than in winter, in other words, the presence of water tends somewhat to equalize temperature throughout the year.

During winter, farmers and gardeners may often notice that young plants are more or less completely thrown out of the ground, and this can only take place in land that contains a considerable amount of water. Wheat and clover plants, for instance, are often thrown out so completely that the field has to be broken up in spring, and some other crop sown in the place of that which has been destroyed. The result is brought about by the conversion into ice of water in

the soil, with the accompanying increase in volume that always accompanied such a change. That the surface of the ground is raised during the continuance of frost is convincingly shown by the fact that field gates and garden doors, which usually swing quite freely, may become firmly fixed to the soil. When ground is heaved up by frost the plants are raised with it, and when the ice is converted into water the plants tend to sink back to their original position, but their roots never quite attain to the level from which they started. If this process of heaving-up under the influence of frost is frequently repeated during winter, the plants may be left entirely exposed on the surface of the ground, no part of their roots being retained below the surface. It follows, therefore, that the worst type of weather conditions, from this point of view, is that which is associated with frequent alternations between frost and fresh, which, continued throughout a winter, will produce much more disastrous results than a long-continued frost, with the temperature at a lower range.

It is a matter of experience that the process of drainage is associated with earlier harvests, a result due to the fact that dry land can not only be sowed earlier, but,

being warmer, plants have the opportunity during summer of maturing more quickly.

It is found that stock are healthier on land that is well drained than on land that is water-logged, certain specific diseases in sheep, such as foot-rot and liver-rot, being more or less associated with, or, at least, intensified by wetness. In the case of pasture, it is found that when the surplus water is withdrawn by artificial drainage, poor plants, like sedges and rushes, have a tendency to disappear, better plants, including clovers, making headway amongst the herbage.

On dry land, also, a greater variety of crops may be grown than on wet land, and these crops may be utilized in a different fashion. Roots, for instance, can scarcely be grown upon land that is over-wet, and if grown they can only be utilized by being carted off the land and consumed at the homestead, or upon some drier part of the farm. Folding, for instance, which is such a common method of utilizing roots on dry land, is impossible on land that is overcharged with water. Where land is distinctly wet, the chief tillage crops are wheat and beans, but when land has been drained this small list may be extended to include mangolds,

turnips, swedes, cabbages, red clover, oats, and others. Crops are better nourished on land from which the surplus water has been withdrawn, not only because manures decompose and humus nitrifies more quickly, but also because supplies of food are brought forward to the roots more steadily and continuously. On land saturated with water plants can only utilize the plant food in the immediate neighbourhood of their roots, and when this is appropriated they necessarily suffer from lack of nourishment. But when drains are put into land water is steadily and continuously attracted towards them, that is to say, there is a constant movement of the water throughout the soil in the direction of the means of escape now provided. Water, therefore, is no longer stationary, but in motion, so that fresh supplies of soluble food are constantly being brought within range of the feeding roots, with consequent advantage to the crop.

One great advantage of drainage in the case of tillage land is that the land can be more easily and more thoroughly cleaned, in fact it is the difficulty of getting rid of weeds that often puts wet land out of cultivation altogether. If tillage operations and the cleaning of land are rendered easier by

drainage, it means that the working expenses generally are reduced, and if to such reduction is added a considerable increase in the yield, a large net return may remain over after meeting the cost of drainage.

Depending on the cause of wetness, land may be freed of its surplus water by methods of prevention or of cure. It may be possible to hinder water getting on to land, as is the case where rivers are provided with embankments to prevent overflow during periods of flood. Then, again, land that is subject to inundation, owing to the slow current of an adjoining stream, will be rendered less liable to submersion if the course of the brook or stream is straightened, so that flood water may flow away more quickly. This result is due partly to the reduction of friction between the water and the bottom and sides of the stream, and partly to the fact that a straight course is necessarily the shortest course between any two points, and thus the fall of the water is relatively increased. If, for example, the distance between two points, A and B, on a winding stream is 800 yards, and the difference in level is 6 feet, the fall is 1 in 400. Should a straight channel be cut between the two points, the distance that the water has to

flow may be reduced to 400 yards, which would mean a fall of 1 in 200, or twice as much as formerly.

It sometimes happens that fields which slope upwards towards a hill are wet, owing to the outpouring of water along the base of the steep ground. One may often find a series of springs, or, at any rate, moist spots, along a certain level on a hillside, the water being forced to the surface at these points, owing to the dip and character of the strata of which the hill is composed. If, for instance, the strata dip towards the north there may be springs along the north side of the hill but none along the south side, the rain-water, in fact, that falls upon such a hill sinking down until it meets with some stratum through which it cannot pass, and along this stratum it will flow until it finds its way to the surface on the north side. Having gained the surface of the ground, the water may then proceed to flow over the fields immediately adjoining. Of course such water can be got rid of by the ordinary process of drainage, which consists in constructing parallel drains at comparatively close intervals, and into these drains the water will find its way. But it must necessarily be relatively very expensive to drain

a field of this character in such a way. It will be much cheaper and quite as effective to sink, what is called, a "catch" drain close along the level where the water is found to be rising to the surface, and by this means to intercept the water before it gets on to the field lying at a lower level.

It is not proposed to discuss the technical details of the practice of draining, which can best be learned from a practical surveyor, assisted by reference to a reliable text-book.

An ameliorative process, which in some respects is the exact opposite of drainage, is irrigation, that is to say, the leading of water on to land in place of off it. This process is capable of application only under somewhat limited circumstances. In the first place it presupposes a supply of water in sufficient quantity and of suitable quality. Moreover, irrigation is only successful upon land of somewhat special character. Very indifferent results are obtained by leading water on to land that is so stiff and impervious as to prevent the water filtering through the mass. To obtain good results the land must be sufficiently porous to permit of a large amount of percolation, although it is not suggested that all the water led on to a field should escape only by the subsoil

or drains. Speaking generally, a sandy or gravelly soil is most suitable for the purpose of irrigation. If the land is too strong it is apt to become sour and, in the process of a short time, infertile.

In this country the chief benefit from irrigation is derived from the suspended and dissolved substances that are carried to the soil and to the plants through the agency of the water. The substances in suspension are to a large extent deposited in the soil and tend to change its physical condition. Those substances which are in solution are partly laid hold of by the roots of plants to serve as food. That it is the substances present in the water, rather than the water itself, which confer the benefit, is evident from the fact that if one examines a meadow, especially in the earlier part of the growing season, one can see that the herbage is much more vigorous close to the water channels, than at parts of the field farther removed from the source of supply. The water, more or less charged with plant food, is distributed over the area by means of suitable channels, and those plants growing nearest to the water-courses have necessarily the best opportunity of securing nourishment. The water, more or less deprived of its plant food, then flows to

more distant parts of the area, where the plants, being less abundantly supplied with nutritive materials, grow less vigorously.

In tropical countries, on the other hand, irrigation is undertaken chiefly for the purpose of supplying plants with the necessary water. This being the object, water under these circumstances may contain little if any matter in solution or suspension; and, as a matter of fact, much of the water used for irrigation in India, Australia, and other tropical and semi-tropical countries, is pure rain-water that has been collected and stored in suitable ponds or "tanks," from which it can be drawn for use during the dry season.

The theory of irrigation may be shortly stated as follows. The water necessary for plant growth is supplied and, as has been mentioned, this is the main object in dry countries. Irrigation also regulates the temperature of soil to some extent, tending to make it cooler during summer and warmer during winter. The presence of abundant water in the soil enables certain chemical processes to go on more rapidly than would otherwise be the case, while the weathering of stones is to some extent accelerated. Irrigation also provides a means of clearing the ground of certain noxious insects, and of

other animals, such as mice and voles, but it cannot be said that suitable conditions for use of this kind often present themselves.

All water is not alike suitable for irrigation. Water to be serviceable must be free from acids, such as humic acid, nor must it contain plant poisons, like low oxides of iron. Some water also is unsuitable on account of its containing too much lime, which may sometimes be seen encrusting plants, and other objects, that it encounters. Speaking generally, however, water from limestone rocks, notably Chalk, is largely used for purposes of irrigation. One can gain some idea of the quality of the water by studying the plants in the brook, or other watercourse, from which it is proposed to draw supplies. If these plants are to a large extent of the type represented by Watercress, Speedwell, Crowfoot, Floating Poa, etc., the water may be assumed to be suitable. If, on the other hand, the plants growing in the brook consist of Sedges, Rushes, Reeds, and similar plants, the probability is that the water is bad.

The district of England that shows the widest use of irrigation is the south and south-west, where such streams as the Test, Itchin, Avon, Wiley, and Kennet, are largely utilized for irrigating meadows along their

course, the produce being partly made into hay and partly grazed by stock, especially sheep, which damage the channels less than heavier animals. These streams have their source for the most part in the bottom of the Chalk, their origin being very deep-seated, and, as a consequence, they have a relatively high temperature in winter ; no inconsiderable part of the benefit which such water confers being due to its warming influence upon the soil. It is very interesting, as one passes through one of the southern valleys, to watch the methods by which water is conveyed from the stream, distributed over the area, and finally led back again into the brook. The land, as a rule, is laid out in a series of ridges and furrows, the water being led along the top of the ridge and, by means of suitable barriers, made to overflow, so as to run equally over the land between the crest of the ridge and the bottom of the adjoining furrows. Having done its work it is finally led off the ground by means of channels constructed in the bottom of the furrows.

An ameliorative process, largely practised in the clay districts of England in the earlier years of last century, is what is called Clay Burning. The operation consisted in turning one or two furrows at regular intervals over

the field, and, when the furrow slices had sufficiently dried, the soil was carted to certain points where it was piled in heaps, interstratified with some kind of fuel (generally faggots), and slowly roasted or burned. It was usually considered necessary to apply from 50 to 100 tons to an acre, and the effects were undoubtedly in many cases very considerable. The present low prices of agricultural produce, and the high rate of wages, have combined to make clay burning an obsolete process, and, moreover, the farmer of to-day has a very much wider choice of fertilizing materials than his predecessor of a century ago.

The results of burning clay, and applying the material to the soil, may be summarized as follows. Clay, to begin with, is hydrated silicate of aluminium, and on account of its being hydrated it is plastic and sticky, and, under most conditions of weather, difficult to work. But, in the process of roasting, the water of combination is driven out, and the substance left behind, while still a silicate of aluminium, is no longer hydrated, and, consequently, does not become sticky and plastic when wet. The incorporation, therefore, of a large quantity of burned clay with the natural soil of a field, produces a good

physical effect, resulting in the improvement of natural drainage, the raising of the temperature of the land owing to the water getting more freely away, and the improvement of the physical character as regards tilth and freeness of working. The process of burning also liberates a certain amount of potash, which when the material is spread on the land becomes available as plant food. Then, again, low oxides of iron, which are injurious to plants, are during the process of burning converted into higher oxides, which are not only innocuous but act as fixers of plant food in solution, and may serve as food themselves. These higher oxides are all redder in colour than the low oxides, and this explains why clay that has been burned is always of a much brighter red, than the clay with which one starts. It is for this reason, also, that in many cases bricks are not of the colour of the clay that has been used in their manufacture. It may also be mentioned that the larvæ of injurious insects, and the seeds of injurious plants, are destroyed in the process of burning; but, on the other hand, nitrogen present in the soil is likely to be dissipated in the process.

In former times extensive areas of light land were marled, and in some parts of the

country, notably Warwickshire, almost every field contains a large depression from which marl must have been drawn in great quantities a hundred years or more ago. Marl is essentially clay containing ten per cent. or more of carbonate of lime, and that it is capable of improving soil is evident from the fact that enormous quantities were used in the past, before more concentrated fertilizing agents were placed within reach of farmers.

A form of amelioration that is much in evidence along the tidal reaches of the Ouse, the Trent, and the Humber, is Warping. This can only be practised on low-lying, level land, situated close to a sluggish tidal river. In the estuary large quantities of mud are deposited, and, when the tide rises, this mud is violently churned up, and more so under certain conditions of the river and tide than others. The adjoining land is provided with embankments supplied with suitable sluices, and when the mud-laden tide rises a portion of the water is allowed to flow over the area thus surrounded, where it is retained until most of the mud and silt has been deposited. This having been effected, the water is allowed to escape, when it will be found that a muddy covering, an inch more or less in

thickness, has been left over the surface of the ground. Should this process be repeated during some months or, it may be, a year or more, the level of the ground may be raised several feet. The material so deposited is rich in plant food and, although rather impervious and difficult to work, it is very suitable for the growth of certain kinds of crops, notably wheat and potatoes. In the course of time, the improved conditions thus effected tend to disappear, when the operation must be repeated.

An ameliorative process which has had a great vogue in the past, and which is still fairly extensively practised throughout the country, is Liming. Lime is an essential element of plant food, and where the percentage of lime in soil is very low it is possible that artificial dressings may have a directly beneficial effect upon crops. But it is not for the purpose of supplying plant food that lime is usually applied, and therefore the application of lime must be classed as an ameliorative rather than as a manurial process.

Lime may be applied in various forms, but for the most part it is used in the condition of burned lime, which is either ground into powder and distributed while in the unslaked condition, or is allowed to absorb moisture

from the air, when it becomes slaked and is then spread upon the land. In the past, practically all burned lime was allowed to slake before being applied, but more recently many lime works have erected a grinding plant, through which the lumps of burned lime are passed as they come from the kiln, the fine powder so produced being distributed on the land before much of it has passed into the slaked condition. It is doubtful whether the effect of unslaked lime is greater than that of the slaked form, but grinding is a convenient way of securing equal distribution throughout the soil, and it also facilitates the application of smaller dressings. It is now a common practice to apply 10 to 30 cwt. of ground lime per acre, and under certain circumstances it is probable that the results justify the cost. But in many cases it is doubtful whether the application of lime, either slaked or unslaked, produces much effect. This is one of the matters that must be considered by each farmer individually, and it is only possible to obtain reliable indications that may be applied in practice by instituting field trials.

Large dressings of lime are chiefly used for the purpose of eradicating or preventing that troublesome disease of turnips called

finger-and-toe. While this disease can be checked to a considerable extent by rational methods of cultivation, there is no doubt that the most effective method of controlling it is through the agency of periodic dressings of lime at the rate of about 5 tons per acre. When, however, the cost of the material, and the expenses of carting and spreading, are taken into account, a dressing of 5 tons per acre represents an outlay of not much less than as many pounds, and such an outlay is more than most land can bear in the present condition of the agricultural markets. There has therefore been a tendency of recent years to rely more on the effects of dressings of 20 to 30 cwt. of ground lime, costing, with labour, about £2 per acre. While it cannot be contended that a small dressing of ground lime is as effective as three or four times this quantity of ordinary burned lime, still, as a preventive rather than a curative measure, it is probable that the use of this newer form of lime is justified. Not only does lime counteract finger-and-toe through making the soil alkaline, but it also facilitates nitrification, and supplies a necessary element of plant food, so that several advantages are attendant on its use. Buyers, however, have to be more on their guard in the purchase of ground lime

than of common burned lime, for whereas, in the latter case, impurities like ashes and stones can be readily detected, in the former case everything is ground up into an impalpable powder, so that it is impossible by mere inspection to determine, even approximately, the extent of the impurity. Ground lime should therefore be brought under a specific guarantee of purity, which generally falls somewhere between 80 and 90 per cent.

Another form of lime, extensively employed in agriculture, is Gas Lime which, when thoroughly weathered so that the poisonous substances (sulphides) are rendered innocuous, has a distinctly beneficial effect on many classes of soil, though experiments go to show that as a preventive or cure of finger-and-toe it is much less effective than burned lime.

More recently, ordinary unburned limestone as it comes from the quarry has been passed through disintegrators, and may now be purchased in the form of powder, but it is doubtful whether in most cases this form of lime is effective enough to be profitable.

In certain districts of England great quantities of chalk have in past years been applied to agricultural land with, it may

be assumed, satisfactory results, but at present it is on the whole rather rare to find land being thus treated. The quantity used was often as much as 20 or 30 tons per acre, and the labour of digging, carting, and spreading this amount involved a high outlay that few farmers would now care to face.

The effects of applying lime in any form may thus be shortly summarized. It attacks the humus with the ultimate formation of nitrates, and where land is rich in organic matter this is probably its main effect. It also reacts upon the natural silicates in the soil and liberates a certain amount of potash, which then becomes available as plant food. Lime also tends to sweeten soils, that is to say, it neutralizes organic acids and induces an alkaline reaction, a condition of things which is inseparable from high fertility. By neutralizing acids, lime also makes soil unsuitable for the life of the organism that causes finger-and-toe in turnips and other cruciferous plants. Lime has also useful physical effects on soil, making clay more friable and therefore more easily worked, and raising the absorptive power of lighter soils, but it is doubtful whether these results alone will often justify the heavy expenditure necessary to secure them.

An ameliorative process that is still largely practised on the heavy lands of England, especially in our drier districts, is Bare Fallowing, that is, the leaving of a field without a crop during a whole season. It is a process that is not now so common as formerly, though, in 1910, in Bedfordshire 1 acre in 11 of the tillage area, in Huntingdon 1 acre in 12, and in Essex 1 acre in 13, was under bare fallow; which contrasts with 1 acre in 876 in Cumberland, and 1 acre in 1516 in Haddington. The average for the whole of England in 1910 was 1 acre under bare fallow for 31 acres of tillage, or fully three per cent.; while for Scotland the corresponding figures are 1 to 546, or less than one-fifth per cent. It is extremely doubtful whether so high a percentage of bare fallow as prevails in certain districts of England is justified, for if land cannot be kept under cultivation except by periodically missing a crop, it is probable that, on the whole, it would pay better to lay the land away to permanent grass. Then, again, it is not infrequently possible to grow a cleaning crop, such as mangolds, cabbages, swedes, turnips, or beans, and thus avoid the necessity of bare fallowing.

The objects of bare fallowing are various.

Probably in most cases land is left uncropped during a summer, in order that advantage may be taken of the dry weather thoroughly to clean it, an operation which on strong, plastic clay is difficult between the separation of one crop in autumn and the sowing of another crop in spring. But if a farmer is prepared to sacrifice a season's growth it is possible, by means of repeated ploughings and harrowings, during the dry weather of summer, to get the weeds effectively eradicated. Bare fallow is in most cases followed by winter wheat. At the time of the final working of the fallow, usually in the month of August, the land is generally dressed with about ten or twelve loads per acre of farm-yard manure, which is at once ploughed into the ground, wheat being sowed in the end of September or throughout October. As much of the success of this crop depends upon getting the seed into the land in good time, crops that follow bare fallow are generally more productive than those following root crops such as mangolds or swedes, which are not usually removed from the land much before the end of October. Seeing that the land must subsequently be ploughed, it means that, unless the weather is unusually favourable, wheat after a root crop cannot

usually be sowed until the early part of November, and often much later, and such delay is generally reflected in the yield.

Careful investigations at Rothamsted and elsewhere have shown that during the season of bare fallow there is a very considerable formation and accumulation of nitrates in the land, resulting for the most part from accelerated nitrification consequent on thorough aeration of the soil during the process of bare fallowing. The superior success of the wheat crop after a bare fallow is probably due to a considerable extent to the abundant supply of nitrates with which it is provided. In respect of this, however, much depends on the character of the weather in autumn, which, if wet, results in serious leaching of the soil, with consequent loss of the nitrates formed during summer. Weathering is also facilitated by the process of bare fallowing, the frequent exposure of stones to the atmosphere encouraging their disintegration. Lastly, it may be mentioned that bare fallowing a field for a season, in place of putting it under a crop of turnips, is one means of combating the disease of finger-and-toe, which may be very prevalent in a crop grown upon any particular field once in four or five years, but which may be

entirely absent if a cruciferous crop has not occupied the land oftener than, say, once in eight or ten years.

Against these advantages of bare fallowing, apart from the loss of nitrates, are to be put the heavy expenses which, with cultivations, rent, and rates, often amount to £5 or more per acre. No single wheat crop could bear this outlay, in addition to its own costs, but, of course, the effects of a bare fallow are not confined to the crop immediately following, but are shared by several.

CHAPTER V

THE PRINCIPLES OF MANURING—THE NITROGENOUS MANURES

ON tillage and grass farms alike, the selection and application of fertilizing substances is one of the most important matters that demand the farmer's attention. Nowadays there are but few farms, with any considerable amount of land under the plough, where artificial manures are not employed to a greater or less extent. It is only on purely pastoral hill farms that

artificial manures can be altogether dispensed with, though one also finds an almost self-sufficing condition of things, as regards manure, on some of the large Down farms of the south of England.

In approaching the subject of manuring, one may be disposed to ask why manurial substances are applied at all. Various answers may be applied to such a question ; one that is frequently given being that manures are applied in order that crops may be grown, the practice of manuring being now so common that many assume the impossibility of obtaining any crop at all without the use of manure. This answer, however, is not satisfactory, inasmuch as plenty of instances are to be found where crops of a sort are annually produced without the return to the land of any natural or artificial fertilizing material. One has an example of this in certain meadow land, which from time immemorial has neither been irrigated nor manured, and yet from which annually a fair crop of hay is taken. In such a case the plants are supplied with nourishment from the materials that are annually rendered available in the soil through the action of weathering agents, and if the conditions of weathering are specially

favourable—and assuming also that there are large stocks of potential nutriment—the system can no doubt be practised indefinitely. The permanent meadow land at Rothamsted furnishes an example of what can be obtained, throughout a long series of years, from unmanured ground. Ever since 1856 two plots of land there have received no manurial treatment, and annually the hay crop is reaped and carried off. The yields obtained during the past fifty-six years show a gradual diminution, but even now, in an average season, a crop yielding about three-quarters of a ton of hay per acre is being obtained. One of the wheat fields at Rothamsted similarly contains a plot which has received no manure for more than sixty years, and at the present time the yield is practically steady in the neighbourhood of 13 bushels of grain and half a ton of straw per acre. This, of course, is a yield which is less than half the average produce of the wheat lands of Great Britain, but it is as great as the average of the returns of wheat in the United States of America. After sixty years without manure, the barley crop at Rothamsted is also producing a considerable annual return, amounting as it does to about 10 bushels of grain and a

third of a ton of straw per acre. It cannot be said, therefore, that the application of manure is in all cases necessary to produce crops, although in productiveness such crops may be much below the average of those grown upon land otherwise treated.

Another answer that may be given to the question "Why do we manure?" is that manure is used in order to supply crops with plant food. As regards their requirements in the matter of food, farm crops show marked variations. A crop of cereals, grain and straw, will, on the average, remove from an acre of land about 50 lb. of nitrogen, and 20 lb. of phosphoric acid; while a crop of turnips, bulbs and leaves, will similarly remove about twice as much nitrogen and fifty per cent. more phosphoric acid; whereas mangolds take from the land about fifty per cent. more nitrogen, and an even larger proportion of phosphoric acid than a crop of turnips. As regards potash, the variations are also very wide, turnips, for instance, removing about 150 lb. per acre, as contrasted with less than 30 lb. in the case of wheat. It is possible, by ascertaining the weight of soil upon an acre of land, together with a chemical analysis, to determine approximately the quantity of plant

food that is naturally present in soil. If we regard only the top 12 inches, we have to deal with 43,560 cubic feet of soil per acre; and, assuming a weight of 100 lb. per cubic foot, the top 12 inches of soil works out at 4,356,000 lb. per acre. Frequently the percentage of nitrogen is about 0·1, the percentage of phosphoric acid about 0·2, and the percentage of potash about 0·4; and on this assumption the surface soil contains 4356 lb. of nitrogen, 8712 lb. of phosphoric acid, and 17,424 lb. of potash per acre. On the basis of this estimate, therefore, an acre of ordinary land contains enough nitrogen to satisfy the requirements of a cereal crop for nearly a hundred years, while the phosphoric acid and potash, if available, would meet the demands of the crop for more than four hundred and five hundred years respectively. And yet with these enormous supplies of plant food in the neighbourhood of the roots, it is a matter of everyday experience that the use of, say, 1 cwt. of nitrate of soda, supplying less than 20 lb. of nitrogen per acre, is followed by marked effects. The reason for this result is, of course, that the plant food naturally present in the soil is not, for the most part, immediately available, whereas the material

that we supply in the form of artificial manures is capable of serving at once, or almost at once, as plant food. Bearing in mind the fact, therefore, that there are superabundant stores of nutritive materials in most land, it is evident that we cannot say that manuring is undertaken to furnish plant food that is non-existent ; but, rather, that manures are applied in order to provide crops with food in a form in which it is not naturally present in sufficient quantity in the land.

At one time it was believed that the requirements of crops as regards manures could be ascertained by chemically investigating the soil ; but the figures just quoted show that the ordinary method of chemical analysis, which merely shows the total percentages of soil ingredients, is practically valueless for this purpose. Of late years much attention has been given to determining the availability of the nutritive materials present in the soil, and especially as regards phosphoric acid and potash. In place of extracting these substances by means of strong hydrochloric acid, analysis has proceeded on the lines of preparing a solution containing a small percentage of a weak solvent (1 per cent. of citric acid) ; the percentage of phosphoric acid and potash

which it dissolves from the soil in a definite time, and under definite conditions, being taken as an indication of the percentage of these substances that is immediately available as the food of crops. It cannot be denied that the results thus obtained are of considerable value as a guide to manuring, especially under extreme conditions; that is to say, such a method of analysis enables one to conclude with considerable confidence whether a soil undoubtedly requires or does not require the addition, let us say, of phosphoric acid or potash. But in the case of a soil which is neither very rich nor very poor in these substances, it is doubtful whether such determination of "availability" is of much value as a guide in the practice of manuring.

While it cannot be said that we apply manure to land in order to grow a crop, or to furnish something previously non-existent, it can with confidence be said that manuring is undertaken in order to obtain a full crop, in other words, a crop that is economically profitable. It has always to be remembered that a large part of the yield of any crop goes to meet the standing expenses of the farm; and if the yield is only sufficient to meet such expenses it is evident that

no profit will remain to the cultivator. But if the yield can be considerably increased at a reasonable expenditure on manure, it will be found that the net profits of the farm are rapidly improved, because the standing expenses of growing large crops are proportionately less than those of producing small ones.

In considering the principles of manuring, one must give particular attention to the Law of Minimum, which may be stated thus: That the yield of a crop depends upon the available supply of that essential element of plant food that is present in least amount. Put into other words, the law implies that no superabundance of plant food generally can compensate for deficiency in an essential element. In popular language, the law may be illustrated by a chain, whose strength is necessarily determined by the weakest link. All the higher plants, and therefore all farm crops, require to have access to ten elements of food, that is to say, no plant can grow unless every one of these ten elements is present, and no crop can give a full yield unless they are all present up to the requirements of the crop. These elements are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium,

magnesium, iron, and calcium. But although every one of these ten elements is necessary for the growth of plants, we do not require to supply them all in manure, because, in the atmosphere or in the soil, several are naturally present in abundance. Except under unusual circumstances, the only three substances that the farmer requires to consider, from the point of view of manuring, are nitrogen, phosphorus, and potassium, the two latter being usually designated under the name of their oxides, and called, respectively, phosphoric acid and potash. No doubt there are exceptional cases where lime (calcium) is so deficient in the soil that crops cannot obtain all their requirements; but, as a rule, lime is employed rather as an ameliorative than as a directly nutritive substance. Again, magnesia (magnesium) may occasionally fall below the necessary quantity, but it is rare that actual experiment has proved this to be the case.

Confining our attention, therefore, to the three elements that are of most importance in manuring, we find numerous illustrations of the working of the Law of Minimum in the published results of the station at Rothamsted. Thus, the average yield of hay for upwards of forty years was 23·2 cwts. per acre without

manure, 26·1 cwts. where about $3\frac{1}{2}$ cwts. of ammonium salts were annually employed, and 23·3 cwts. where about the same quantity of superphosphate was used ; whereas from the plot receiving both ammonia and superphosphate an average yield of 35·5 cwts. of hay was annually obtained. These figures show that phosphoric acid used alone in the form of superphosphate has produced the quite insignificant increase of one-tenth cwt. of hay, and although nitrogen, in the form of ammonium salts, similarly employed, has done a little better, the increase over the unmanured land is only 2·9 cwts. of hay per acre. On the other hand, when superphosphate was added to ammonium salts it was accountable for 9·4 cwts. of hay, and when ammonium salts were added to superphosphate the yield of hay was increased by 12·2 cwts. The aggregate increase, in fact, of these two substances used on separate areas was only 3 cwts. of hay, but when applied together to the same land they produced an increase of hay amounting to 12·3 cwts. These figures show that this land at Rothamsted is deficient in both phosphoric acid and nitrogen, so that when only one of these substances is employed the increase is quite insignificant, for the reason that it is

the necessary element present in least amount (in this case nitrogen and phosphoric acid respectively) that determines the yield.

Similar results appear from the barley experiments, which have been continued since 1852. Whereas $3\frac{1}{2}$ cwts. of superphosphate added only 4·8 bushels to the crop when used alone, it was responsible for an increase of 13·4 bushels when used as an addition to ammoniacal manure. Similarly with regard to 200 lb. per acre of ammonium salts, which, when used alone, increased the crop by 11·2 bushels, whereas when added to superphosphate they were accountable for 19·8 bushels.

Not only does the Law of Minimum indicate that an intelligent farmer should take steps to discover which is the weakest link in the chain of nutritive substances in his land, but it also shows that weakness in any one link cannot be compensated for by strengthening other links. If, for example, the natural supplies of nitrogen in the land are deficient, no improvement in the crop can take place by the use of additional supplies of phosphoric acid or potash.

The Law of Minimum is usually considered in relation to manures, but it is equally applicable to any other essential condition

of growth. Not only do plants require to be fed with suitable substances, but their growth is also determined by other necessary conditions, as, for example, a plentiful supply of oxygen, a suitable temperature, and the requisite degree of moisture. If, for instance, oxygen is deficient in the soil, no conditions of temperature, however favourable, will compensate for insufficient aeration. Or everything may be satisfactory save temperature, and, again, growth will be unsatisfactory or non-existent until this limited factor is put right.

According to the manurial element that they contain, artificial fertilizers are classified as nitrogenous, phosphatic, or potassic, or a combination of these terms. The two most important manures that furnish nitrogen alone to plants are Nitrate of Soda and Sulphate of Ammonia; but to these there have recently been added two others, nitrate of lime and calcium cyanamide, which are prepared by inducing the free nitrogen of the atmosphere to enter into chemical combination under the stimulus of electric discharges. In addition to the four purely nitrogenous manures just mentioned, there are such subordinate substances as Rape Meal, Blood Meal, etc., but these are of comparatively little importance.

With a possible choice of at least four nitrogenous manures, varying somewhat in composition and in price, it becomes of importance that farmers should be able intelligently to select the particular substance best adapted for their special requirements. Up to the present the choice has lain almost exclusively between nitrate of soda and sulphate of ammonia, and on the basis of equal quantities of nitrogen there are special circumstances that point to the one rather than the other as being best suited for any particular case. Something depends upon the crop to which the manure is to be applied. Speaking generally, nitrate of soda acts better than sulphate of ammonia as a top-dressing, partly because when one top-dresses a crop one desires immediate action, and this is got from nitrate of soda, and partly because it sinks more quickly and more deeply into the ground and so comes more effectively within the range of the roots of the plants. Moreover, when a crop already occupies ground to which manure is applied, chances of waste are reduced to a minimum, and this is a consideration of greater importance in regard to nitrate of soda than to any other manure except nitrate of lime. Sulphate of ammonia, on the other hand, is "fixed" or "absorbed"

to a great extent by the superficial layers of the soil, and therefore does not reach the roots of a top-dressed crop with sufficient rapidity. Of these two manures nitrate of soda is the better for application to the hay crop, and this chiefly because we have hereto do with a crop that can only be manured by top-dressing, so that the added plant food must find its way down through a greater or less depth of soil before reaching the roots. The superior merits of nitrate of soda, as contrasted with sulphate of ammonia, as a top-dressing for hay, are well illustrated in the long series of experiments conducted on the permanent meadow at Rothamsted. Without exception, nitrate of soda has produced a much heavier crop of hay than ammonium salts, and botanical analysis has shown that the hay is also of superior quality. Nitrogen in the form of ammonia is largely retained in the surface soil, and it has therefore the effect of encouraging the development of shallow-rooted plants, such as Sheep's Fescue, *Agrostis*, Yorkshire Fog, Sweet-scented Vernal, and Smooth-stalked Meadow Grass; whereas nitrate-nitrogen, by sinking deep into the soil, encourages the growth of plants whose roots are similarly disposed, notably Meadow Foxtail, Tall Oat Grass,

Rough-stalked Meadow Grass, and Perennial Ryegrass. The herbage, therefore, of the nitrate plots, being deeper rooted, is better able to withstand drought ; and this characteristic, combined with the more extensive feeding range of the deep roots, has reacted beneficially on the yield. It may be added, also, that an acid condition of the soil, induced by the long-continued use of ammonium salts, has encouraged the increase of Sorrel, and the same cause has markedly repressed the growth of the Leguminosæ.

Other things being equal, sulphate of ammonia is relatively more suitable for application to turnips and potatoes, because in the case of these crops the manure can be thoroughly incorporated with the soil, and, moreover, growth taking place at a time of year when the micro-organisms of the soil are specially active, ammonia is quickly brought into a condition in which the plants can utilize its nitrogen. But although sulphate of ammonia appears to be relatively well adapted for use on root crops generally, notable exception is furnished by the mangold crop, which at Rothamsted has responded in a very marked manner to the use of nitrate of soda as contrasted with sulphate of ammonia. The causes of the

superior effect of the former manure are probably rather complex. Nitrate of soda sinks more easily and to a greater distance into the soil, and the roots of the mangold crop, following the nitrate, occupy a much more extended range of feeding ground, and so are brought into contact with supplies of potash naturally present in the soil which they can utilize. While it cannot be maintained that soda can replace potash in the economy of the plant, it is possible that certain physiological processes may take place by the aid of soda where potash is not available, and thus the soda of the nitrate of soda confers a benefit upon the crop which is excluded in the case of the sulphate of ammonia. That there are good grounds for this suggestion appears to be proved by the fact that whereas the mangold crop at Rothamsted responds in a very striking manner to the use of potash in the presence of ammoniacal dressings, there is no such marked response where potash is employed in the presence of dressings of nitrate of soda. The conclusion would therefore appear to be justified, that in the latter case potash is not so much required, because, as has been indicated, the soda has to a certain extent acted as a substitute.

The cause of the superior action of the nitrate of soda may also depend in part on the fact that, by encouraging deeper extension of the roots, the crop is placed in a better position to withstand the effects of drought. This cause, however, would operate in the case of all crops, although it may be more emphasized with the mangold crop.

It may also be mentioned that when nitrate of soda is applied to land, the soda may displace a certain amount of potash from natural combinations in the soil, and the potash so liberated will become available for the use of plants.

The action of these two manures depends also to some extent upon the character of the soil to which they are applied. There is much greater danger of nitrate of soda being washed out of the land than is the case with sulphate of ammonia, and therefore, other things being equal, one would be disposed to favour the use of sulphate of ammonia on light, porous sands and gravels, and especially if lime is known to be abundant. Moreover, such soils, being well aerated, offer conditions favourable to the nitrification of the ammonia, and thus encourage its early use by plants. On the other hand, nitrate of soda is better adapted for strong land, where the dangers

of loss by washing are at a minimum, and where the conditions for nitrification are, as a rule, not wholly satisfactory. On account of its attracting water from the air, the continued use of nitrate of soda in large quantities upon strong clay may result in the soil getting into bad mechanical condition, but this result is unlikely to attend the use of nitrate of soda in ordinary agricultural practice.

The experiments at Rothamsted and Woburn have shown very conclusively that, to give its best results, sulphate of ammonia must be used on soil containing a fairly high percentage of lime. At both these stations the annual use of ammoniacal salts has frequently resulted in great reduction of fertility; in fact, at Woburn, the barley and wheat plots getting liberal annual dressings of this manure for over thirty-five years have long since become absolutely barren. Chemical examination of the soil has shown that it is markedly acid, and that practically all the lime has been removed from it. This result has been produced by the acid of the ammoniacal manure entering into combination with the lime of the soil, the latter being removed in the form of soluble calcium salts. That this explanation is satisfactory appears to be confirmed by the fact, that when a

comparatively small amount of lime was added to soil that had been brought into this condition, fertility was immediately restored and satisfactory yields were obtained. Sulphate of ammonia, therefore, would appear to be specially adapted for use upon chalky soils, and others derived from rocks containing a high percentage of lime.

Climate also is not without influence in determining the special suitability of one or other of these two manures. On account of the ease with which rain water removes nitrate of soda from soil, one should rather hesitate to use it in a district of high rainfall, or, at all events, other things being equal, preference would be given to the other manure. Conversely, nitrate of soda would appear to have an advantage over sulphate of ammonia in the drier districts of the East and South of England, and especially if the soil is heavy.

But after giving full consideration to these various questions, a farmer may still be in doubt as to which manure to employ, and in the end his choice will probably be determined by considerations of cost. When the two manurial substances under consideration are of standard quality, sulphate of ammonia, as compared with nitrate of soda, contains

nitrogen in the proportion of about 100 to 75, so that the former manure stands practically always at a higher price per ton than the latter. The basis of purity in the case of nitrate of soda is generally 95 per cent., whereas sulphate of ammonia can usually be purchased under guarantee of 97 per cent. of purity. With these figures before us, it is easy to calculate what the relative amounts of nitrogen are in the two manures. Nitrate of soda when pure is a chemical substance, of which every 85 lb. contain 23 lb. of sodium, 14 lb. of nitrogen, and 48 lb. of oxygen. Of these three substances it is only the nitrogen that interests us in the present connection, and if 85 lb. of nitrate of soda contain 14 lb. of nitrogen, 95 lb. will contain 15.6 lb. Seeing that nitrate of soda is generally purchased on a basis of 95 per cent. of purity, it means that 100 lb. of this manure, as commercially obtainable, hold 15.6 lb. of nitrogen. It therefore follows that if 100 lb. of commercial nitrate of soda contain 15.6 lb. of nitrogen, a ton will hold 350 lb. At the present time, nitrate of soda costs about £10 per ton, so that the 350 lb. of nitrogen which the ton contains are being purchased upon a basis of 6.9 pence per lb.

Sulphate of ammonia is a substance of which, when pure, every 132 lb. contain 28 lb. nitrogen, 8 lb. hydrogen, 32 lb. sulphur, and 64 lb. oxygen. But, like nitrate of soda, this substance is not used for manurial purposes in a chemically pure condition, the degree of purity being usually 97 per cent. By calculation we find that if 132 lb. of pure sulphate of ammonia contain 28 lb. of nitrogen, 97 lb. will contain 20·6 lb. Seeing that 97 per cent. of purity is the basis upon which we usually purchase this manure, it follows that the percentage of nitrogen in ordinary commercial sulphate of ammonia is 20·6. From this it can be calculated that a ton of commercial sulphate of ammonia contains rather over 461 lb. of nitrogen, and at present the price is about £12 per ton. On this basis it will be found that the price per pound of nitrogen in sulphate of ammonia is 6·3 pence, as contrasted with 6·9 pence in the case of the nitrate of soda. At the prices we have assumed, therefore, sulphate of ammonia is better value than nitrate of soda to the extent of rather over $\frac{1}{2}$ d. per lb.; and if, in other respects, it is a matter of indifference which substance we employ, we should unhesitatingly give the preference to the former.

In ordinary commercial practice in this country, these and similar nitrogenous manures are generally valued not on the basis of so much per pound of nitrogen, but by what is called the system of units. As illustrating this system we may take the two manures under consideration and adhere to the prices of £10 and £12 per ton respectively. To find the value per unit of nitrogen in the case of the nitrate of soda we divide the price per ton (£10) by the percentage of nitrogen (15·6), and the result is 12·82 shillings—say 12s. 10d. Similarly treating the sulphate of ammonia, we divide £12 by 20·6, when we find that the value of a unit of nitrogen is 11·65 shillings—say 11s. 8d. There is therefore a difference of 1s. 2d. per unit of nitrogen in favour of the sulphate of ammonia. Multiplying 20·6 by 1s. 2d. we get £1, 4s., which, when added to £12, gives us the price per ton, £13, 4s., at which we might purchase sulphate of ammonia, and still get as good value as is represented by nitrate of soda at £10 per ton. Or, we get at the same result if we multiply 20·6 by 12s. 10d.=£13, 4s., and from this deduct £12=£1, 4s., and the latter is the usual way of making the comparative calculation. On the other hand,

with sulphate of ammonia at £12 per ton, that is 11s. 8d. per unit of nitrogen, we find, by multiplying 15·6 by 11s. 8d., that the corresponding price for nitrate of soda is £9, 2s. per ton.

It was at one time common to speak of nitrogen and ammonia almost as if they were interchangeable terms. Merchants, too, often stated the percentage of their manures both in terms of nitrogen and ammonia, and sometimes even in terms of ammonia only. This was frequently done in order to attract the eye of a possible buyer with a larger figure, the relationship between nitrogen and ammonia being as 14 is to 17. In other words, 17 lb. of ammonia consist of 14 lb. of nitrogen chemically combined with 3 lb. of hydrogen; so that, for instance, the statement that a manure holds 8·5 per cent. of ammonia, is no better than saying that it holds 7 per cent of nitrogen. It is now, however, illegal to omit to state the percentage of nitrogen, if any, in the invoice that must accompany the delivery of a manure.

Valuation by units is a rapid and useful method by which farmers may estimate whether manures that are offered to them are cheap or dear. Some Agricultural

Societies issue annually to their members, usually in spring, a statement of the unit values of standard manurial substances. By means of these units, or of others which the farmer can readily work out for himself, it is easy to ascertain whether manures that are offered are worth the money demanded or not. If, for instance, in any one year standard nitrate of soda containing about $15\frac{1}{2}$ per cent. of nitrogen has a unit value of 12s., that would mean that the price of a ton should be £9, 6s. Supposing that another sample of nitrate of soda were offered containing only 14 per cent. of nitrogen, the corresponding value per ton would be £8, 8s.; but having regard to the fact that the lower the quality the relatively higher is the cost of carriage, it must be said that £8, 8s. is rather too high a price to pay for the lower-quality manure. Certainly if more than this price is demanded—as is most likely, for poor manures are seldom cheap—it is relatively dearer than the other at £9, 6s. If, on the other hand, it can be purchased much below £8, 8s., then it is relatively the better value.

If, after considering the various factors that determine one's choice of a nitrogenous manure, the farmer has still a difficulty in

deciding whether to use nitrate of soda or sulphate of ammonia, he cannot do better than apply both, either separately or in mixture. Field experiments have shown conclusively that on the average of soils and seasons one will usually get a larger crop by applying half dressings of both nitrate of soda and sulphate of ammonia to the same area of land, than by using only one or other of these two substances. The gain in yield may not be striking, but, in the case of the turnip crop, for instance, it may amount to as much as a ton per acre, and the value of this weight of roots is much more than sufficient to compensate for the extra labour of mixing the two manurial substances. Sometimes, indeed, the crop given by the mixture will be greater than the crops grown by either of the two substances used alone. The reason of the superior action of the mixture would appear to be that it furnishes two kinds of nitrogen, one of which acts quickly, and the other more slowly. The former, therefore, nourishes the crop in the early part of the season, while the latter becomes operative somewhat later, at a time, namely, when the effects of the other are on the wane.

Of late years considerable attention has

been given to the two new nitrogenous manures, Calcium Cyanamide or Nitrolim, and Nitrate of Lime. Both are produced by bringing the free nitrogen of the atmosphere into chemical combination; nitrolim, as a result of decomposition in the soil, furnishing plants with ammonia, while nitrate of lime, of course, supplies nitrate nitrogen. Experiments seem to show that these two manures may be used for practically all purposes that are now served by the old standard nitrogenous manures, and so far as yield of crop is concerned there seems very little to choose between them, where equal quantities of nitrogen are employed. Calcium cyanamide is rather a dusty substance, and therefore somewhat troublesome to sow, but this difficulty can be readily got over in various ways, such as damping, or mixing with superphosphate. It generally contains about 18 per cent. of nitrogen, that is to say its composition approaches that of sulphate of ammonia; while nitrate of lime holds about 13 per cent. of nitrogen, a composition somewhat below that of nitrate of soda. They may be valued, for commercial purposes, on the prices current per unit of nitrogen in sulphate of ammonia and nitrate of soda respectively. While

experimental evidence goes to show that there is little difference in the effects of the two new substances, preference may on the whole be given to nitrate of lime, which, being a natural plant food, is at once available for the use of crops.

As regards such a source of nitrogen as Rape Meal or Dried Blood, it may be said that, as a rule, the unit value on the market is much too high; and, moreover, the nitrogen content (about 5 per cent. in the case of Rape Meal) is so low that the cost of carriage and carting is relatively high. The nitrogen, too, is in the organic form, and slower in its action than any of the four nitrogenous manures mentioned above. The circumstances must be very rare where a farmer would be justified in purchasing rape meal or dried blood as a source of nitrogen.

CHAPTER VI

PHOSPHATIC, PHOSPHATIC-NITROGENOUS, AND POTASSIC MANURES

COMING now to a second group of artificial fertilizers, we may consider the leading forms

of purely phosphatic manures, of which by far the most important are Superphosphate of Lime and Basic Slag. The former is obtained by treating ground phosphatic rock with sulphuric acid, during which process most of the raw insoluble phosphate is converted into a form soluble in water. In former times superphosphate was frequently put on the market in somewhat poor mechanical condition, a state of things due partly to the character of the rock phosphate employed, and partly to defective manufacture. Of late years, however, manufacturing details have been more carefully attended to, and the mechanical condition of superphosphate now seldom leaves anything to be desired.

Basic slag, which has come into such general use during the last twenty years, is a bye-product in the manufacture of steel from pig-iron, which contains considerable quantities of phosphorus. In the manufacture of steel it is desirable to get rid of the phosphorus, and this is effected in a converter by blowing air through the molten iron mixed with lime until all the phosphorus is oxidized to phosphoric acid, which is then withdrawn as a phosphate of lime in the slag that forms on the surface of the molten mass, and in the lime bricks which line the walls

of the converter. The slag and bricks are subsequently ground into an impalpable powder, which is the material the farmer purchases and applies to his land as a phosphatic manure. As in the case of nitrate of soda and sulphate of ammonia so here, a farmer has to weigh very carefully the advantages and disadvantages of purchasing basic slag as compared with superphosphate of lime. There is little doubt that superphosphate, containing as it does soluble phosphate, is more rapid in its action than basic slag, and, consequently, for immediate effect, the former manure is to be preferred. But any objection to basic slag on the score of slowness of action can be overcome to a large extent by looking ahead; so that if it is desired, for instance, to dress a root crop with basic slag it can be applied to the land some months before the time when the crop will occupy the ground. During this interval the insoluble phosphate of the slag will be acted upon by the natural solvents of the soil, so that a considerable proportion of the phosphoric acid will be immediately available when the plants require it.

Except from the point of view of rapidity of effect, basic slag would appear to possess advantages that are superior to those associ-

ated with superphosphate. Basic slag is pre-eminently adapted for use upon grass land, and especially on land that has for some years been under pasture. Probably one reason why basic slag is capable of exerting its best effects on old grass land is that under such circumstances the soil contains a considerable amount of humic and carbonic acids, which are formed during the decomposition of the vegetable matter. These weak acids react upon the slag, and appear to be sufficient to make a large proportion of the phosphate immediately available for the use of plants. While basic slag generally produces superior effects on grass land, it must be said that its action is most of all emphasized where there is any tendency towards sourness in the soil. This condition of things is indicated by the presence of certain plants, such as Bent Grass, and more particularly the so-called Carnation Grass (*Carex glauca*). Whereas superphosphate, being an acid substance, increases the acidity of soil, basic slag, being alkaline, tends to counteract acidity, and this action is to the advantage of all crops.

It is often asserted that basic slag has little effect on grass land where the soil is sandy or gravelly, or even where there is a marked tendency in this direction. Under these

circumstances superphosphate would also produce little effect, and the reason in both cases is, not that the physical conditions of the soil are unsuitable for the action of the manures, but that on light, gravelly soil the growth of White Clover cannot be markedly stimulated. Unless this plant can be induced to grow luxuriantly, at least in the earlier years of the renovation of a pasture, the final and permanent improvement that is our object will not be secured. It is a matter of common observation that White Clover grows best upon land that is well-consolidated. Why this should be so may not be clear, but at least there is nothing strange in a plant making very specific demands as to the character of the habitat in which alone it will grow well. Such pronounced peculiarities are well known amongst garden flowers, and growers, to be successful, must take great pains to provide the right conditions of soil and moisture. On fields which possess soil of an open texture it may be found that White Clover is abundant only along the side of a footpath that may cross the field, or in the neighbourhood of a gate round which stock have a tendency to congregate. In both cases the ground has been consolidated by treading, and thereby the conditions have

been improved for the growth of this particular plant. But throughout the body of the field there may be little evidence of the presence of White Clover, and under these circumstances the use of a phosphatic manure would probably produce little effect. If, however, the land is well-consolidated—and this is the state of things in clay and clay loam—White Clover appears to find conditions thoroughly congenial to its growth, provided it can secure the necessary amount of phosphatic nourishment. We may walk across an unimproved field of this character and with difficulty find any considerable number of plants of White Clover. Some would say that none are present; but careful observation will, as a rule, detect the presence of more plants than are at first obvious, but the plants are so small and starved that they frequently consist of no more than two or three leaves, and only rarely are they sufficiently strong to produce a flower. When, however, basic slag or superphosphate is applied to such land the results are often little short of marvellous. In the first year after the application of the fertilizer no great change may be visible, although in respect of this much depends upon the season. If the weather is very dry, the first year may

pass without any appreciable results being obtained ; on the other hand, if the summer is genial and sufficiently moist the phosphatic manure will have asserted itself long before the growing season is over. But it is in the second and subsequent seasons that the transformation is so striking. Land which was almost barren, and of a rental value of only a few shillings per acre, has, by the use of basic slag or superphosphate, been transformed into a pasture so rich as to be capable of fattening stock, and of commanding a rent of more than a pound per acre.

Although the prime factor in such improvement is wild White Clover, it sometimes happens that almost as good results are obtained where the leguminous plants naturally present in the land are Trefoil (*Medicago lupulina*), or Bird's-foot Trefoil (*Lotus corniculatus*), or Kidney Vetch (*Anthyllis vulneraria*), or Red Clover (*Trifolium pratense*). In the great majority of cases, however, the plant that is stimulated by the phosphatic manure is White Clover, and it is hardly too much to say that without the presence of this plant the striking results obtained by phosphatic manures on grass land could not be secured. In this connection it may be said that it seldom matters

whether basic slag or superphosphate of lime be used, but if basic slag does not succeed, there must be few cases where a better result would attend the use of the other substance.

The course of the history of a pasture field which is improved by phosphatic dressings may be thus described. In the first year little result, if any, may be obtained, in the second year the effects are usually very striking, and in the third year they are equally so or even better. At this stage, in the month of July, the herbage may appear to consist of little but clover, which probably, if it be sorted out and weighed, constitutes about 50 per cent. of the whole. From the third or fourth year onwards a change comes over the character of the herbage. White Clover, and leguminous plants generally, become relatively scarcer, their place being taken by a stronger growth of grass. The grass, however, which supplants the White Clover is much superior, as a rule, to what the latter had previously displaced in the second and third years. On the kind of land where phosphatic manures produce their greatest effect, the commonest plant is usually Bent Grass, that is to say, some species or variety of *Agrostis*. This grass is

not appreciated by stock, which will hardly eat it,—at least during summer,—if better herbage is to be obtained. It is, to a large extent, suppressed by the luxuriant growth of clover which follows the use of phosphatic manure; but when the clover is in its turn partially displaced, the grasses that follow are generally Poas, Fescues, Fox-tail, Yellow Oat Grass, and Cock's-foot. While grasses become more conspicuous about the fourth year, and tend to increase in subsequent years, White Clover does not by any means completely disappear, although it is usually much less abundant than in the earlier stages of the improvement.

The cause of the reduction in quantity of the clover would appear to be associated in some way with the phenomenon that is known as Clover Sickness, which, as is well known, prevents the growth of Red Clover, except at considerable intervals, on many classes of tillage land. While the causes of Clover Sickness are not fully understood, it would appear to be likely that some restricting factor is induced to assert itself in consequence of the too frequent or over-luxuriant growth of clover; and one way by which the trouble may be overcome is to desist from the attempt to cultivate Red

Clover on the particular field until the land has had a "rest." Many leguminous plants are subject to some such "sickness," and as all must have healthy colonies of bacteria on their roots for successful growth, the conclusion would appear to be justified that the sickness of the plant is closely associated with sickness amongst the bacteria. Whatever the reason, there is no doubt as to the fact that White Clover, which may have been very abundant two or three years after phosphates were applied, becomes comparatively scarce. But after the clover has remained on a lower level of productiveness for some years, it generally responds to a repeated dressing of basic slag, although not to the same extent as in the first instance; so that the most rational method of treating such land would appear to be to apply a substantial dressing (7-10 cwt. per acre) of a phosphatic manure to begin with, and to supplement this after an interval of five or six years with a smaller dressing (4-6 cwt. per acre). Although superphosphate of lime has a stimulating influence upon clover, it is rarely that one sees quite such striking results from the use of this substance as those which follow the application of basic slag.

While it is popularly supposed that basic slag is not superior to superphosphate on light soil under grass, it is probably not maintained that there is any difference in the effects of the two substances upon light land under cultivation. The great majority of field trials on roots have shown that there is little to choose as regards effect, where equal quantities of phosphoric acid are supplied in the two forms of basic slag and superphosphate of lime, provided the former be applied a month or two before the crop is sown. Certainly where equal money value of these two substances has been the basis of comparison, the results in the case of root crops have generally been in favour of basic slag. At prices hitherto current for these two manures, one has been able for the same expenditure to obtain about one-third more phosphoric acid in the form of basic slag than in superphosphate of lime. So satisfactory has the former manure proved, that it would not be surprising had the price risen to a higher level. But old customs have great tenacity, and superphosphate of lime, having been used by farmers for three-quarters of a century, has attained a position from which the other substance has experienced a difficulty in dislodging it.

The alkaline character of basic slag places it in a superior position for use on a cruciferous crop which it is intended to grow on land known to be affected by finger-and-toe. Experiments have shown that this disease is encouraged by acidity in the soil, and superphosphate cannot fail to increase acidity to a greater or less degree, whereas basic slag tends to counteract it.

This prejudicial effect of the acidity of superphosphate is so generally recognized that a manure, known as Basic Superphosphate, has been placed on the market, the main character of which is that, by the addition of lime in the process of manufacture, the originally water-soluble phosphate has been rendered insoluble, while the acidity has been more than neutralized. The insoluble phosphate thus formed is known as "reverted" phosphate, which, although insoluble in water, is soluble in a 2 per cent. solution of citric acid, and is therefore on equal terms of "availability" with the phosphate of basic slag.

The acid character of superphosphate can also be neutralized by mixing this substance with basic slag, and experiments have shown that such a mixture gives excellent results. It may be adopted with advantage

where one has a difficulty in deciding which of these two manures to use alone.

The two substances just described are the most important of the purely phosphatic manures. A third, namely, Precipitated Phosphate, has given an excellent account of itself in field trials, but home supplies seem to be so firmly held for export to Japan, Honolulu, the Mauritius, etc., that little is available for the British farmer. It is chiefly a bye-product in the manufacture of gelatine, glue, and similar substances from bones, the phosphate of which is rendered soluble by acid and subsequently precipitated by the addition of lime. Raw Mineral Phosphate, too, ground to a fine powder, has been employed with fair success on sour meadows, but the bulk of this substance is not used as manure till it has been made into superphosphate. Bone Ash, again—a substance imported from South America, where bones are often used as fuel—supplies little but phosphate, and, when ground up, a certain amount comes on the market as manure.

The valuation of phosphatic manures may proceed on one or other of the lines indicated when dealing with nitrogenous manures. On the Continent the system adopted is to

determine the quantity of phosphoric acid contained in 1000 kilograms, say a ton, of the substance to be valued ; and, knowing the price per ton, one arrives at the cost per pound. This system may be illustrated by taking the case of basic slag, which is put on the market of different qualities, the phosphoric acid usually varying between 10 and 20 per cent., corresponding to a percentage of phosphates of about 22 to 44. A common type of basic slag is one that holds 37 to 42, say 40, per cent. of total phosphates, which corresponds to a percentage of phosphoric acid of 18·32. The relationship between phosphoric acid and total phosphates may be explained as follows. The chemist, in analysing a phosphatic manure, determines the amount of phosphoric acid, and this, by calculation, he converts into tribasic calcic phosphate, the substance, namely, that is meant when one uses the shorter term "phosphate" or "phosphates." The basis of the calculation is the chemical constitution of tribasic calcic phosphate, 310 lb. of which contain 168 lb. of lime, united chemically with 142 lb. of phosphoric acid. If, therefore, 142 lb. of phosphoric acid can combine with 168 lb. of lime to form 310 lb. of tribasic calcic phosphate, 18·32 lb. will

combine with the proportionate amount of lime to form 40 lb. of tribasic calcic phosphate, the equation being $\frac{310 \times 18.32}{142} = 40$.

If 310 be divided by 142 we get 2.2 (nearly), and this figure can be used as a multiplying factor to convert phosphoric acid into terms of phosphate; or as a dividing factor, in making the change from phosphate to phosphoric acid. In the basic slag, therefore, that we have assumed, there is 18.32 per cent. of phosphoric acid, so that a ton holds 410 lb. of this substance. Assuming that the basic slag costs £2, 10s. per ton, free on rail, this will mean that the phosphoric acid is being purchased at the rate of just under 1½d. (really 1.46d.) per pound. It is easy, therefore, to calculate what will be the price of a ton of any other quality that may be quoted at any particular rate per pound of phosphoric acid.

In this country, however, phosphatic manures are not usually valued in this way, but by the system of units, and we have already seen the working of this method in connection with the valuation of nitrogenous manures. In the case of basic slag holding 40 per cent. of total phosphates, and costing f.o.r. £2, 10s. per ton, the value

of a unit is got by dividing the price per ton by the total percentage of phosphates, namely 40, when the price per unit will be found to work out at 1s. 3d. Using this unit value to assess the corresponding price of other samples, we should find, for instance, that a slag guaranteed to contain 35 per cent. of phosphates would be worth £2, 3s. 9d. per ton; while one holding only 28 per cent. of phosphates would, at the same rate of unit valuation, be worth £1, 15s. per ton. It is probably hardly necessary to point out that the more concentrated slags have some value beyond their "equivalent" price, where railway charges and cartage are heavy. On the other hand, low-grade slags contain more free lime, and buyers may be inclined to allow something for this.

During the past few years the opinion of chemists has gone in the direction of valuing slag, not upon its total contents of phosphoric acid or tribasic calcic phosphate, but only upon the quantity soluble in a 2 per cent. solution of citric acid. Basic slag is not soluble in water, and although its phosphate becomes available with considerable rapidity, it cannot be made use of by plants until it has been dissolved by

the weak acids in the soil, or by the substances exuded by plant roots. It is believed that a certain proportion of the phosphate of slag is much more readily available than the remainder, in fact it is probable that a considerable residue is so insoluble as to have no practical value. An attempt has therefore been made to differentiate between what is easy of absorption by plants and what is not; the standard agent now universally employed for this purpose being a 2 per cent. solution of citric acid, in which the basic slag is left for half an hour, during which it is subjected to continuous shaking. The phosphate removed from the slag by this weak solvent is supposed to be a fair indication of what farm crops are able, within a reasonable time, to make use of; a common basis of sale being a total citric solubility of 80 per cent., that is to say, the vendor guarantees 80 per cent. of the total phosphate to be soluble in the said solution, when manipulated in the authorized manner. On this basis a guarantee of 32 per cent. of citric-soluble phosphate is equivalent to a guarantee of 40 per cent. of total phosphate, and many vendors now sell basic slag only on such a basis of solubility, though the total phosphate must also be mentioned.

This method of selling, which has now received statutory sanction in this country, has long been practised on the Continent.

Various theories have been advanced to account for the comparatively easy solubility of phosphate in basic slag as compared with, for instance, phosphate in natural rock. It is not necessary in this place to enter into the details of the various considerations that have been advanced, suffice it to say that in some way or another the phosphoric acid in basic slag is rather loosely united with part of the lime, and in consequence is separable with comparative ease through the action of the weak acids in the soil, or of those exuded by the roots of plants.

Experiment has shown that the solubility and therefore the value of a basic slag are largely influenced by the degree of fineness of the particles. This has led to the setting up of a standard of fineness, namely, that 80 per cent. of the material as delivered to the farmer shall pass through a sieve containing ten thousand apertures to the square inch of surface, and this is the grade of fineness that should be insisted upon in the purchase of this manure.

Superphosphate of lime can be valued in the same way as basic slag, and although on

the Continent the substance is generally bought on the basis of a certain price per pound of phosphoric acid, in this country valuation is invariably made on the system of units. In superphosphate there is generally a small percentage of phosphate that has not been dissolved by acid, but this is disregarded for the purposes of valuation. It is only the phosphate which is soluble in water that is taken account of, the percentage of such soluble phosphate usually lying between 25 and 30 per cent., though it may run both higher and lower. Assuming a sample containing 30 per cent. of soluble phosphate to be offered at £2, 15s. a ton, the value of a unit will be found, by dividing £2, 15s. by 30, to be 1s. 10d. Utilizing this unit-value we thus find that a superphosphate containing 28 per cent. of soluble phosphate will be worth £2, 11s. 4d. a ton, while a superphosphate containing 35 per cent. of similar phosphate will have a value of £3, 4s. 2d. per ton. If the slag is bought upon a basis of citric solubility, it is a simple matter to determine the corresponding value per unit, and such value can be similarly utilized in determining the price that should be paid for varying qualities bought on this basis.

Of the manures at the farmer's disposal containing both phosphates and nitrogen, those of greatest importance are Bones in their various forms of Crushed Bones, Bone Meal, Steamed Bone Flour, and Vitriolated, Vitriolized, or Dissolved Bones. Bones have been used in one form or another for a very long time, and are associated in farmers' minds with a period when agriculture was more prosperous than of late, and in this way they have attained to a position to which their intrinsic merits hardly entitle them. Of recent years many experiments have been conducted on the value of bones in one form or other, as compared with a corresponding quantity of phosphoric acid and nitrogen derived from other sources—such as superphosphate, basic slag, nitrate of soda, and sulphate of ammonia—and it has been found that when put to this test bones do not come well out of the ordeal. In their undissolved condition they are most serviceable when ground to a fine powder, in which form they are put on the market under the terms bone meal, or bone flour. Bone meal contains everything that the natural bone holds, except the oils and fats, which have been removed in the process of boiling. Bone flour is simply another name

for bone meal, but steamed bone flour, on the other hand, has had a considerable amount of its gelatine removed by the action of superheated steam, and this has resulted in a large reduction in the percentage of nitrogen. But both these forms of bone are found to be comparatively slow in their action; in fact it is probable that a considerable proportion both of the phosphates and nitrogen is never utilized by plants, or utilized so slowly as to be practically valueless. It cannot be recommended, therefore, that at present prices bones in any form should be employed wherever cheaper and more efficient substances can be obtained.

Pure bone meal holds up to 50 per cent. of total phosphates and about 4 per cent. of nitrogen, and if the former be valued at 1s. 3d. per unit—the approximate value of phosphate in basic slag—and if the nitrogen be similarly valued at 11s. 8d. per unit—namely, the price per unit of nitrogen in sulphate of ammonia—the value of a ton works out at £5, 9s. 2d. For something like this price bone meal can at present be purchased; but there is no doubt that in the great majority of cases a better return will be obtained from a similar expenditure

on the other phosphatic and nitrogenous manures just mentioned.

Steamed bone flour generally contains about 60 per cent. of phosphates and $1\frac{1}{2}$ per cent. of nitrogen, and, utilizing unit values as above, the price per ton works out at £4, 12s 6d., a price, however, that is distinctly below the market rate.

In the case of dissolved bones, a greater or less percentage of the phosphate has been rendered soluble by the use of sulphuric acid, and converted into the same "soluble phosphate" as that in superphosphate of lime. Assuming that the dissolved bones contain 15 per cent. of soluble and 20 per cent. of insoluble phosphates, together with 3 per cent. of nitrogen, we can value the soluble phosphate at 1s. 10d.—the unit-value already applied to superphosphate of lime—and the insoluble phosphate at 1s. 3d.—the unit-value for basic slag—while the nitrogen may be valued at 11s. 8d., as in sulphate of ammonia. Using these figures we arrive at a total price per ton of £4, 7s. 6d., a figure, however, which is lower than that at which pure dissolved bones can generally be purchased. As a matter of fact the unit-values of the constituents of dissolved bones are more likely to be 2s. 9d. for the

soluble phosphate, 1s. 3d. for the insoluble phosphate, and 15s. for the nitrogen, and at these rates the price per ton works out at £5, 11s. 3d. It is evident, therefore, that the price of dissolved bones is generally at least £1 per ton in excess of their intrinsic value; and at the present market value for bones of all kinds, in comparison with other forms of nitrogen and phosphates, most farmers will probably abstain from purchasing them.

Other manures, containing both nitrogen and phosphate, that may be mentioned are Phosphatic Guano (1-2 per cent. nitrogen, up to 60 per cent. insoluble phosphate); Fish Guano (6-8 per cent. nitrogen, 10-15 per cent. insoluble phosphate); Meat Meal (6-8 per cent. nitrogen, 10-25 per cent. insoluble phosphate); and Blood Meal (10-12 per cent. nitrogen, and about 5 per cent. phosphate); and when any of them can be bought on a satisfactory basis of unit-values they are worth consideration.

The great source of the various kinds of potash manure employed throughout the world is the district round Stassfurt, a town to the north of the Harz Mountains in the centre of Germany. There, at a depth of 700-1500 feet, are to be found beds, two or

three hundred feet thick, of a natural deposit of various kinds of potassic and other salts; which, having been ground up, are put on the market either in their natural condition or after undergoing certain methods of artificial concentration. The commonest potash manure is Kainit, a natural salt containing about 23 per cent. of sulphate of potassium (including a small amount of chloride of potassium), which is equivalent to $12\frac{1}{2}$ per cent. of pure potash. The materials present in kainit, beside sulphate and chloride of potassium, are sulphate and chloride of magnesium (27 per cent.), chloride of sodium or ordinary salt (36 per cent.), and a small quantity of gypsum. While nothing in kainit is valued except the potash, it is well to bear in mind that fully one-third of the total weight consists of common salt, and for this reason a preference would be given to kainit for the treatment of crops to which it was desired to apply salt.

The relationship between pure potash and sulphate of potassium, usually called sulphate of potash, is apparent when it is stated that 174.2 lb. of sulphate of potash contain 94.2 lb. of pure potash, combined chemically with 80 lb. of sulphuric acid. It follows, therefore, that if kainit is guaranteed to

contain $12\frac{1}{2}$ per cent. of potash, this is equivalent to a guarantee of 23·1 per cent. of sulphate of potash. There is a tendency on the part of the seller to state the percentage of sulphate of potash rather than the percentage of pure potash, because the former is a larger figure, and therefore more attractive to a certain class of buyer. Under the Fertilisers and Feeding Stuffs Act, however, a seller is bound to state the percentage of potash, whether the percentage of the sulphate is also given or not. If kainit contains $12\frac{1}{2}$ per cent. of potash, it follows that one ton will hold 280 lb. ; and, assuming a price of £2, 5s. per ton, this means that the potash which it contains is costing 1·93d. per pound. On the Continent it is the custom to sell kainit and other potash manures on this basis, but in this country valuation is generally made on the system of units. On the basis of the figures stated above, we find—dividing £2, 5s. by $12\frac{1}{2}$ —that the unit-value of the potash works out at just over 3s. 7d. (strictly 3s. $7\frac{1}{8}$ d.).

If one desires a more concentrated potassic fertilizer, also containing its potash in the form of sulphate, it can be obtained by purchasing one or other of the manures that are put on the market under the name

of Sulphate of Potash. One of these is generally guaranteed 50 per cent. pure, which, on the basis of the figures already given, is equivalent to a guarantee of 27·04 per cent. of potash. A ton, therefore, holds 606 lb. of potash, and if this be valued at 1·93d. per pound, it works out at a price per ton of £4, 17s. 6d. Or we can multiply 27·04 by the price per unit (3s. 7d.), and, of course, we arrive at the same result. A still more concentrated form of sulphate of potash, guaranteed 80 per cent. pure (=43·2 per cent. potash), can be obtained, and the price per ton may be worked out in a similar manner. Which of these three manures to employ will depend partly on considerations of carriage, and partly on whether one wants to apply considerable quantities of common salt to the crop or not. If this be desired, then the preference would be given to kainit. The mangold crop is one which, in many cases, is benefited by dressings of common salt; and certainly in the case of this crop, other things being equal, the preference would be given to kainit. On the other hand, if no special value is attached to salt, the farmer would naturally prefer to use a more concentrated manure than kainit, because, by so doing, costs of carriage and

cartage, as well as the labour of distributing are reduced.

Farmers have also at their disposal a manure in which the potassium is not combined with sulphuric acid but with chlorine, this manure appearing on the market under the names of Chloride, or Muriate of Potash. It is generally sold of a high degree of purity, usually about 90 per cent., which is equivalent to a guarantee of 56·85 per cent. of potash. The calculation here is a little more complicated than in the case of the sulphate. Every 74·6 lb. of chloride of potash (strictly speaking, chloride of potassium) consists of 39·1 lb. of potassium combined chemically with 35·5 lb. of chloride. A 90 per cent. sample of chloride of potash, therefore, holds 47·2 per cent. of potassium $\left(\frac{39\cdot1 \times 90}{74\cdot6} = 47\cdot2\right)$. Now, potassium is not potash, but it can form it by uniting with oxygen; 78·2 lb. of potassium combining with 16 lb. of oxygen to form 94·2 lb. of potash, so that 47·2 lb. of potassium will form 56·85 lb. of potash. This figure, therefore, is taken to represent the potash hypothetically present in a 90 per cent. sample of chloride of potash. A ton, therefore, contains 1,272 lb. of potash, and if this be valued at 1·93d. per pound, the price

will work out at £10, 4s. 7d. Or, employing the system of units, we can multiply 56.85 by 3s. 7d., when, of course, we come to the same result. If, therefore, considerations of carriage and cartage are serious, one would be disposed to select this form of manure rather than the less concentrated forms previously mentioned. Many experiments have been carried out with the view of determining whether potash is best employed in the form of sulphate or of chloride, but it cannot be said that crops display any very special preferences for the one as compared with the other. What should therefore determine a purchase would be considerations of carriage and cartage, and, more particularly, the price per unit at which the various manures are offered.

As regards the crops to which potash may with advantage be applied, it may be said that it is only under very exceptional circumstances that cereals need a potassic dressing. When barley is grown upon very light land a considerable increase is sometimes got from the use of potash, but in the case of wheat and oats a potassic dressing is practically never required. It is for roots, potatoes, and leguminous crops that considerations of potash are most important. In the case of

turnips and swedes receiving fair dressings of farmyard manure, potash can seldom be employed at a profit, but where artificial manures are alone depended upon in the treatment of these crops it will not infrequently be found that potash is of the utmost importance. Cases are known to those who have followed experimental work of recent years where, on light soil, no amount of nitrogen or phosphates, unassisted by potash, is capable of producing anything like a full yield. Under these circumstances it will be found that at an early stage the turnip or swede plants get into an unhealthy condition, which is indicated, not only by feeble growth, but by a yellow blotchy condition of the leaves. Where, therefore, a farmer is dependent upon artificial manures alone for the turnip or swede crop, he ought to take steps to ascertain by a simple field experiment whether he should apply a potash manure, and in the great majority of cases it will be found profitable to do so. The potato crop is even more dependent upon artificial assistance from potash than the turnip crop, and even when farmyard manure is employed an addition of potash manure to the value of 10s. to 12s. per acre will usually be found to be profitable. Potash

in excess, and especially chloride of potash, has a tendency to depress the percentage of starch in potatoes, but in ordinary practice such a result will seldom be likely to arise.

Of all the root crops, mangolds are most dependent upon a supply of available potash in the soil. One of the most interesting and important results of the long-continued experiments at Rothamsted has been obtained in the continuous growth of mangolds. There it was found, on the average of a long series of years, that superphosphate and ammonium salts, without potash, produced little more than $7\frac{1}{2}$ tons of roots per acre, whereas the addition of a fair dressing of potash produced an average crop of 14 tons per acre. Where superphosphate and nitrate of soda were used, without potash, the crop was nearly $15\frac{1}{2}$ tons per acre, and when potash was added to this dressing the yield was not increased. It is evident, therefore, that potash has proved very effective in the presence of ammonium salts, but has been inoperative in the presence of nitrate of soda.

Various reasons may be advanced to account for these results. Nitrate of soda is known to sink deep into the soil, and this deeper diffusion of the plant food in-

duces the root system to develop correspondingly, in order that the plants may secure the nitrogen which—though not without an effort, as it were—is obtainable. Other things being equal, plants with an extensive root system are likely to obtain larger quantities of such substances as potash, naturally present in the soil, than plants with more restricted roots. But it is also believed that the soda of the nitrate of soda can to a certain extent replace potash in the nutrition of plants—perhaps more so in case of some plants, *e.g.* mangolds, than of others. It is not suggested that potash is an unessential element of plant food in the case of mangolds, but it is probable that abundance of soda, whose properties in many respects agree with those of potash, makes it unnecessary that such a crop should have access to such large quantities of potash as would otherwise be required. As has already been pointed out, also, it is probable that nitrate of soda can liberate a considerable amount of potash in the soil, which thus becomes available for the use of plants.

Where leguminous crops are grown upon medium and lighter soils, they often respond markedly when additions of potash are

made to phosphatic dressings. This applies to lucern, sainfoin, all the clovers, and markedly so to peas—a crop more frequently grown on light soils than most other leguminous crops. Vetches and beans, on the other hand, being more associated with cultivation on heavy soil, do not usually respond, under ordinary practice, in any very marked degree to dressings of potash; but if the soil is light, or if for any other reason it is deficient in this ingredient of plant food, these crops will show the effects of its use as much as any.

It is perhaps in connection with the manuring of permanent grass land that one hears most discussion as to the use or otherwise of potash. On the meadow land at Rothamsted it has been found, as the average result of more than fifty years' work, that the withholding of potash from a mixed artificial dressing has resulted in a very marked reduction in the yield of hay, with a more than proportionate deterioration in its quality. Potash was found to encourage the growth of the better grasses, and notably the growth of clovers and other leguminous plants; and what between quantity and quality there is no doubt that the use of potash on such land as that at Rothamsted, and

similarly managed, is thoroughly justified. But it is to be remembered that the permanent grass plots at Rothamsted are not treated on any system that is met with in commercial farming. Two crops of hay are cut annually, or at least in those years when the season permits of a second crop being taken, and the whole of the produce is consumed off the ground, no farmyard manure being returned to the plots under consideration. Under these circumstances it is not surprising that potash has been found to influence the yield in a very marked degree. But in ordinary practice permanent meadow land is dressed once in three or four years with farmyard manure, with or without artificials in the intervening years. If farmyard manure is not available, artificials alone are depended on, but in any case it is rare in Britain for two crops of hay in a season to be taken off unirrigated permanent grass land; any growth that comes after the hay crop is removed being pastured by live stock, which necessarily furnish manurial residues to the land. Where farmyard manure is applied to grass land at reasonably short intervals, it is rare that the use of potash in artificial mixtures during the intervening years produces a profitable result.

Where farmyard manure is not available, cases become more numerous where potash will justify its inclusion in an artificial dressing, and yet even under these circumstances—and assuming that the land is grazed by stock during autumn and winter—potash will often be found to have very little effect. One of the most conclusive experiments bearing upon this point is that which has been going on for fifteen years at the Northumberland Experimental Farm near Morpeth. Two sets of plots on that farm are separated by a highway; and on one side are the rotation experiments, which demonstrate in the most convincing manner that without farmyard manure a turnip crop practically cannot be grown in the absence of potash. On the other side of the road are the permanent grass plots, where not only does the addition of potash to phosphates, with or without nitrogen, produce no increase in the hay, but its tendency on the whole is markedly in the direction of reducing the yield. The reduction of yield as a result of using potash is specially striking where this substance is used alone or in the presence of nitrogen only. On these plots it is only when potash is added to phosphates, without nitrogen, that a small increase in the yield of

hay is obtained. This, combined with some improvement in quality, has justified the use of the potash ; but, as in the case of so many other details of manuring, no one can come to any reliable conclusion as to whether potash should be used or not without carrying through an accurate field experiment.

With regard to the treatment of permanent pasture, as contrasted with hay, one can only refer to the exhaustive series of experiments conducted in different parts of Great Britain, and reported on in a Supplement to the January issue of the *Journal of the Board of Agriculture* in 1911. In the case of these experiments the results were gauged by the effects exerted by the manures upon the growth of sheep, and in no case was it found that potash could be profitably employed. As is pointed out in the report, it is much less likely that potash will be required on pasture than on hay. Stock, grazing a pasture, are constantly dropping potash in the form of solid and liquid excreta on the surface of the ground. This potash was, of course, in the land before, but much of it was so deep down as to be beyond the reach of any but the deeper-rooted plants. By them, however, it is absorbed and conveyed to the leaves and stems, and when

these are consumed by stock the potash is restored to the ground; but it is now in the surface layers, and therefore within the feeding range of such shallow-rooted plants as White Clover.

There is only one class of manure that contains in considerable quantity all three of the more important elements of plant food, namely Guanos. The most important guano is that which comes from Peru, of which, however, the imports are now much less than in the middle and earlier half of last century. Good Peruvian guano is an excellent fertilizer, offering to plants nitrogen (7-12 per cent.), phosphates (20-40 per cent.), and potash (3-4 per cent.) in an easily available form. Worked out on a unit basis, however, it will be found that the price looks high (£7-£10 a ton), a position that it has attained partly on its intrinsic merits, and partly as an inherited tradition of the good agricultural times, when high profits and Peruvian guano were closely linked in the farmer's mind. Ichaboe guano, a South African product, has much the same composition and value as Peruvian. There are, however, other guanos on the market which hold much less nitrogen (2-3 per cent.) and much more phosphate (50-70 per

cent.), but these, while costing less, are distinctly less effective.

All true guanos consist of excreta of sea-birds. If the deposits are comparatively fresh the nitrogen is high and the phosphate low in quantity, but, in both cases, high in quality. But the deposits may have lain so long that much of the nitrogen has been washed out, and what remains is comparatively inactive. With advancing decomposition the phosphates increase in quantity, but become less soluble, so much so, indeed, as to be of little service till dissolved by sulphuric acid, as in the manufacture of superphosphate.

CHAPTER VII

THE EFFECTIVE USE OF ARTIFICIAL MANURES

IN connection with the use of artificial manures generally, the following rules for guidance should be observed. Attention should be given to equal distribution of the dressings, that is to say, the manures should be evenly scattered over the land, and all

tendency to a patchy distribution should be avoided. Patchy distribution results from the use of an imperfect mechanical distributor, or from inefficient hand distribution, or from the continuance of the work during windy weather. Then, again, equal distribution cannot be secured unless the manure is in fine, mechanical condition. Manure at all lumpy cannot fail to produce more or less unsatisfactory results. If, for any reason, the distribution is unequal it must necessarily follow that a certain proportion of the field is over-manured, and other portions correspondingly under-manured. Where too much manure has been applied the plants growing there may be destroyed by poisoning, and especially will this be the case where a highly soluble manure like nitrate of soda is used, or an acid substance like superphosphate of lime. When unequal distribution has not gone so far as to poison the crop in places, it may result in the encouragement of excessive growth at certain spots, and correspondingly reduced growth at others. Such a result would appear in its most undesirable form in the case of the barley crop, whose profits in many cases are dependent upon the securing of a thoroughly equal sample of grain, and

this cannot be obtained unless the crop is approximately of like vigour over the whole area. Where artificial manures are employed on a considerable scale it will well repay a farmer to make an effort to secure a horse distributor of a thoroughly efficient type. Where artificial manures are sown by hand the work must be entrusted to a thoroughly efficient worker. But even the best worker, if he is asked to apply something like a maximum dressing, is sure to attempt to over-fill his hand, with the result that as he removes the handful from the sowing sheet or seed-lip he is sure to drop a certain amount before he begins his "cast." Such patchy work will subsequently become evident in a series of over-luxuriant spots directly along the line that the worker has traversed, and one may depend upon it that over luxuriance at these spots has been secured at the cost of reduced production on other parts of the ground.

Not only does patchy distribution result in over luxuriance at one place and reduced luxuriance in another, but it is also to be borne in mind that the heavier the dressing of manure the greater is the chance of loss by washing into the subsoil or into the drains. The absorptive power of soil, that

is to say, its capacity to fix and retain ingredients of plant food, is in inverse proportion to the quantity of soluble manure employed. The over-manuring, therefore, that results from patchy distribution must, at those points where excessive quantities have been applied, encourage waste of manurial substances.

Then, again, speaking generally, one will obtain better results by applying, let us say, 20 cwt. of nitrate of soda to 20 acres, than by applying the same quantity to 10 acres and leaving the other 10 acres undressed; and similarly with regard to other manures and other quantities. In all agricultural operations it is well to bear in mind the operation of what is called the Law of Diminishing Returns. This law may be popularly expressed by saying that as one increases the dose of anything one does not get a proportionate increase in the yield. If, for instance, 1 cwt. of nitrate of soda per acre results in an increase of 5 cwt. of hay, 2 cwt. of nitrate of soda per acre will not usually result in the production of 10 cwt., but, of something less; and if one goes on increasing the dose one will soon arrive at a point where the extra dressing will actually bring about a decrease in the yield.

Where a crop is top-dressed little can be done to incorporate the manure with the soil, but under other circumstances it is a good plan to work the manure into the land by means of the harrow or cultivator. The passage of these implements tends to improve the lateral distribution, and, at the same time, results in the manure being more completely mixed up with the mass of soil. This helps the soil to fix it, and at the same time it is more completely appropriated by plant roots. The relationship between soil and manure should also be carefully considered. Thus, other things being equal, sulphate of ammonia is preferable to nitrate of soda on light land. Basic slag has an advantage over superphosphate in the case of peaty soil, whereas the reverse may be the case of chalky land. Potash, again, will have relatively more influence where the soil is sand or peat, than where it is clay.

Enough has probably been said to emphasize the desirability of considering the relationship of manures to crops. In the case of barley, for instance, which is a shallow-feeding plant, sulphate of ammonia is relatively of more importance than nitrate of soda, whereas in the case of mangolds the reverse holds true. In the treatment of

permanent meadow land, nitrate of soda is found to encourage deep-rooted plants which, for the most part, are of a better type, and more resistant to drought, than shallow-rooted plants, like Smooth-stalked Meadow Grass and Fiorin, which are encouraged by the use of sulphate of ammonia. Whilst both these nitrogenous manures tend to repress the growth of leguminous plants, this is more marked in the presence of sulphate of ammonia than of nitrate of soda.

Then, again, the inter-action of manures on each other should not be forgotten. Probably every farmer now knows that if sulphate of ammonia or Peruvian guano be mixed with basic slag, the free lime of the latter reacts upon the ammoniacal manure and liberates ammonia, whose escape into the atmosphere can be detected by its characteristic smell. Superphosphate of lime or dissolved bones freshly made, and containing some free acid, will liberate a certain amount of nitrogen if mixed with nitrate of soda. Such a mixture, therefore, should be at once applied to the land, and, if possible, harrowed in. It will also be found that a mixture of superphosphate and kainit will get into a smeary condition if it is allowed to lie too long unused, and especially will this

be the case under humid conditions of the atmosphere. A mixture of basic slag and kainit sometimes "sets" very hard, it should therefore be used without delay. It used to be argued that basic slag and superphosphate of lime should not be mixed together, it being urged that the free lime of the basic slag reacted upon the soluble phosphate of the other manure and caused it to "revert" to an insoluble condition. This, no doubt, is true, but it is doubtful whether reverted phosphate is essentially of less value than water-soluble phosphate, and in any case the mixing of basic slag with superphosphate, or with dissolved bones, will tend to counteract the acid character of these manures; and for certain purposes, notably for use on the turnip crop, where finger-and-toe is to be feared, the neutralization of the acidity is an undoubted advantage.

The many field trials carried out during the last twenty years by Agricultural Colleges, and for a much longer period by the leading Agricultural Societies, have shown conclusively that farmers should not depend too implicitly upon general principles with regard to the use of artificial manures, but should take steps to ascertain the particular requirements of their own farms. This can

easily be done, and, it may be added, only be done through the agency of properly conducted field experiments. Such experiments are not difficult to arrange, nor do they involve a great deal of outlay, but to secure the greatest amount of information, with the minimum amount of trouble and expense, they must be laid down on a well-thought-out scheme. Land of approximately equal character must be made use of, and the plots should be laid down at a sufficient distance from such disturbing agencies as hedgerows, plantations, or isolated trees. They must also be accurately measured, and, later on, the crop should be carefully weighed. In the case of permanent grass land the shape of the plot is not a matter of much importance, but where one is dealing with root crops it is convenient that each plot shall be oblong in shape, say 60 yards in length and 4, or more, in width, the total area of each plot being not less than $\frac{1}{20}$ th acre.

By proceeding upon a well-considered plan, one will get the maximum amount of information from the minimum number of plots. If, for instance, it is desired to ascertain whether, on some particular type of soil, nitrogen, phosphates and potash are all required for the treatment of the turnip crop, and, further-

more, if information is wanted with regard to the actual quantities of these substances that should be employed per acre, one would proceed on some such scheme as this :—

Plot 1. No manure.

Plot 2. 5 cwt. super., 1 cwt. nitrate of soda, 5 cwt. kainit.

Plot 3. No super., 1 cwt. nitrate of soda, 5 cwt. kainit.

Plot 4. 5 cwt. super., no nitrate of soda, 5 cwt. kainit.

Plot 5. 5 cwt. super., 1 cwt. nitrate of soda, no kainit.

By comparing the results on plots 2 and 3, one will ascertain the effects of superphosphate ; by comparing plots 2 and 4 the effects of nitrate of soda will be seen ; and, similarly, by comparing the results on plots 2 and 5 one will learn the effects of kainit. Where the turnip crop is concerned, one may almost assume that phosphate will be required, so that plot 3 might be omitted. It might also similarly be assumed, that a certain amount of nitrogen will be wanted, in which case plot 4 would be dropped from the scheme. But as it can never be assumed that some form of potash will or will not be required it will be necessary to retain plot 5. Simi-

larly it might be argued that plot No. 1, receiving no manure, is unnecessary ; but, as the yield of this plot will prove interesting as throwing light upon the natural capabilities of the soil, it is perhaps on the whole desirable to have an unmanured plot. This simple five-plot test may be extended almost indefinitely, and certainly in the majority of cases it should be supplemented by additional plots. For instance, it is probably desirable to ascertain what is the profitable limit of the use of a phosphatic manure, and for this purpose a sixth plot could be laid down, receiving $7\frac{1}{2}$ cwt. of superphosphate along with the nitrate of soda and kainit of plot 2. By so doing we have the opportunity of ascertaining (*a*) the effects of the omission altogether of superphosphate (compare plots 2 and 3), and (*b*) the effects of a moderate as compared with a large dressing of superphosphate (compare plots 3, 2, and 6). Of course a still larger dose of superphosphate could be tried upon an additional plot, but, for ordinary practical purposes, this is perhaps scarcely necessary. It will, however, be useful, in many cases, to ascertain what amount of nitrate of soda and kainit can be profitably employed, and for this purpose we can add the following plots :—

7. 5 cwt. super., $1\frac{1}{2}$ cwt. nitrate of soda, 5 cwt. kainit.
8. 5 cwt. super., 2 cwt. nitrate of soda, 5 cwt. kainit.
9. 5 cwt. super., 1 cwt. nitrate of soda, $7\frac{1}{2}$ cwt. kainit.
10. 5 cwt. super., 1 cwt. nitrate of soda, 10 cwt. kainit.

By comparing plots 4, 2, 7, and 8, in the order named, we get information with regard to the effects of increasing quantities of nitrate of soda; and similarly by comparing plots 5, 2, 9, and 10, in the order given, information will be forthcoming with regard to the profitable limit in the use of kainit.

Instead of, or in addition to, ascertaining the most profitable quantity of these three ingredients, we might—after plot 5, or after plot 10—proceed to put down additional plots, with the object of discovering the relative effects of superphosphate and basic slag, or of nitrate of soda and sulphate of ammonia, or of kainit and muriate of potash. To compare the relative effects of superphosphate and basic slag we could add a plot receiving basic slag, equal in money-value to 5 cwt. superphosphate, and when this plot is compared with plot 2, the comparative

action of the two phosphatic substances will be indicated. Similarly, if we desire to compare the relative effects of nitrate of soda and sulphate of ammonia, a plot may be dressed with 5 cwt. super., $\frac{3}{4}$ cwt. sulphate of ammonia, and 5 cwt. kainit, when a comparison of the yield of this plot, with that of plot 2, will give information as regards the relative action of these two nitrogenous manures. Similarly with regard to a comparison of the effects of kainit and muriate of potash, 1 cwt. of the latter substance (90 per cent. pure) being about equivalent to 5 cwt. of the former.

Even when every care has been exercised in selecting and measuring the land, and in applying the manures and weighing the crop, one series of plots, confined to a single season without any check, can hardly be expected to give thoroughly trustworthy information. The most reliable line to follow is to duplicate all the plots, and if it is found that there is marked consistency in the yields of the two series, the results may be taken as sufficiently reliable for ordinary practical purposes. But duplicating all the plots means doubling the expense, and, in order to keep down the cost, it will generally be sufficient to duplicate certain of the

plots only; so that if the yields from the plots that are duplicated do not deviate from each other by more than 10 per cent., the tests may be held to be sufficiently reliable. In the above scheme of experiments the plot that had best be repeated, once or oftener, is plot 2. In the five-plot test, therefore, we might have plot 2 (under the designation of 2A) repeated after plot 5, while in the larger scheme involving 10 plots, plot 2 might with advantage be repeated, not only after plot 5, but also after plot 10, when it would be designated as 2B.

The Board of Agriculture have issued a pamphlet dealing with field experiments, and this should be obtained by those desirous of going further into the subject, especially on co-operative lines.

CHAPTER VIII

FARMYARD MANURE

ALTHOUGH we have so far confined our attention to artificial manures, farmyard manure is really of greater importance than any, for the reason that practically every farmer

is called upon to deal with this substance. Farmyard manure is a substance of very indefinite composition, depending as it does for its quality and character upon the food that the animals consume, upon the litter with which they are bedded, and upon the way in which the substance is stored and handled. Speaking generally, it contains about 75 per cent. of water and 25 per cent. of dry matter. The fertilizing ingredients are, of course, entirely confined to the dry material, which holds nitrogen—usually about one-half per cent. of the total weight of manure—and mineral matter. The latter is the so-called “ash” of the chemist, and contains the phosphates, potash, lime, magnesia, and other mineral substances which serve as plant food. Phosphoric acid is usually present to the extent of about one-fifth per cent., while potash and lime amount to about one-half per cent. A ton of farmyard manure will, therefore, contain about 12 lb. of nitrogen, a similar amount of potash, and 4 to 5 lb. of phosphoric acid. From the point of view of plant nutrition, we can, of course, obtain these substances from other sources. Thus we might purchase commercial nitrate of soda to supply the nitrogen, 77 lb. of that substance being

required to furnish 12 lb. of nitrogen, and, assuming the price of the nitrate of soda to be £10 per ton, the outlay on 77 lb. would be 6s. 10d. Similarly, to obtain 12 lb. of potash we might purchase 100 lb. of kainit at a cost of about 2s.; and to obtain 5 lb. phosphoric acid we might select a 30-per-cent.-soluble superphosphate costing £2, 15s. a ton, of which 37 lb. would be necessary, involving an outlay of 11d. Adding these figures together, we obtain a theoretical value for farmyard manure of 9s. 9d. per ton, a sum that is much in excess of its market price. In point of fact, certain considerations combine greatly to reduce the value of farmyard manure below its theoretical level. Thus it has been found at Rothamsted that only one-fourth to one-third of the nitrogen supplied in farmyard manure is utilized by plants, as contrasted with three-fourths in the case of the nitrogen of nitrate of soda. If the fate of the phosphoric acid and potash could thus be followed up, it would probably be found that their availability in farmyard manure is no greater than that of the nitrogen. Then, again, farmyard manure is a very dilute substance, so that large quantities have to be applied to the land to secure a full crop, and the

handling of 10 to 20 tons per acre involves heavy outlay on horse and manual labour. Against this, however, is to be set the fact that farmyard manure greatly improves land, apart altogether from the manurial elements that it supplies. Following the indications given at Rothamsted with regard to the relative value of the nitrogen, we should probably reach a juster estimate of the value of farmyard manure if we divide its theoretical value by two, and take about 5s. per ton as its full practical value—a price, including carriage, that many farmers and market gardeners are prepared to pay.

When a farm animal consumes an ordinary ration it is found that for every 100 lb. of dry matter in the food about 50 lb. reappear, the difference, namely, one-half, taking the form of water and gas in the process of digestion, while a small quantity may be stored up in the form of animal tissue (bone, muscle, fat, hair, etc.).

It is possible to make a calculation of some service for practical purposes, as to the amount of farmyard manure that may be expected from a certain number of animals consuming a normal quantity of food, and being bedded in the ordinary fashion. A well-grown cow or steer, weighing 8 or 9 cwt.,

may be kept on some such daily ration as this: $\frac{1}{2}$ cwt. roots, 8 lb. mixed cake and meal, and a stone of hay or straw. The percentage of dry matter in the roots may be taken as 10, while the corresponding figure for the other food may be put at 86. On this basis it will be found that the animal daily consumes about 24 lb. of absolutely dry food, and will, in addition, require daily at least 6 lb. of straw, calculated dry, as litter. Of the 24 lb. of dry matter consumed as food about one-half will reappear in the dung and urine, while the whole of the litter will be converted into the farmyard manure. We have thus to deal with 18 lb. of perfectly dry substance that daily finds its way to the manure heap. If ordinary farmyard manure contains 75 per cent. of water, we must multiply the 18 by 4 in order to get the daily output of farmyard manure, in the condition in which we find it in the manure heap. Assuming that the farm animals are under cover for six months of the year, this means that an ordinary well-grown cow or steer will contribute between 5 and 6 tons of manure to the general supply. During the time of storage, which on the average may be put at about three months, the farmyard manure

will, as a result of fermentation, lose about 20 per cent. of its organic matter; so that in order to ascertain the approximate quantity that will be available for distribution to the land, we must reduce the weight of fresh dung by one-fifth.

One may also make a useful estimate of the probable output of farmyard manure if one has an approximately accurate idea of the amount of straw at the farmer's disposal for feeding to cattle and for use as litter. It is usually assumed that for each ton of straw consumed at the homestead about 3 tons of farmyard manure should later be available. Suppose the case of a farm of 200 acres which is worked upon the four-course shift, and where, therefore, of the whole tillage area, one-half (100 acres) is under corn crops, and one-fourth (50 acres) under roots. Such a farm will produce about 120 tons of straw, equivalent to about 360 tons of farmyard manure, and if this is distributed equally over half the root break the land will receive about 15 tons of dung per acre, which is approximately what farmers usually expect in practice. This relationship of 1 ton of straw to 3 tons of farmyard manure is also taken as the basis of calculation, when straw is sold off

a farm, as to how much farmyard manure should be brought back to the holding, so that its fertility may be maintained.

Of the constituents of the food, the most important, from the point of view of manuring, is the nitrogen, of which, in the case of fattening cattle, about 96 per cent. reappears in the form of fertilizing material, some 23 per cent. being in the solid form in the dung, and about 73 per cent. in solution in the urine. The balance, namely 4 per cent., is stored up in the animal's tissues in the form of hair, flesh and bone. The nitrogen of the urine is by far the most active and valuable, hence the reason that it is so desirable to prevent the loss of liquids. In the case of a milk cow, however, where milk is sold off the farm, only about 75 per cent. of the nitrogen reappears in the manure, a large proportion of the balance finding its way into the milk in the form of casein and albumen. In the case of growing animals, also, a smaller proportion of the nitrogen will reappear in the excreta, though the proportion so returned is greater than in the case of milk cows. As regards the phosphates and potash, a very small quantity is retained even by animals increasing in weight, more, however, by young growing,

than by mature fattening beasts, so that nearly all becomes available for the use of crops. The larger proportion of the potash appears in the urine, while the most of the phosphates are voided as undigested residues in the dung.

It is possible by means of a calculation to indicate the difference in the quality and value of farmyard manure produced in the one case by fattening steers and in the other case by milk cows. In the case of a cow yielding 700 gallons of milk in the course of the year, the following approximate quantities of fertilizing materials will be removed from the food and diverted to the milk :—

| | £ | s. | d. |
|---|-------|----|----|
| 42 lb. of nitrogen at 6½d. per lb. | 1 | 2 | 9 |
| 16 lb. of phosphoric acid at 1½d. per lb. | 0 | 2 | 0 |
| 14 lb. of potash at 2d. per lb. | 0 | 2 | 4 |
| | <hr/> | | |
| | £1 | 7 | 1 |
| | <hr/> | | |

Assuming that the cow stands in a byre for half the year, producing during that time 6 tons of farmyard manure, the above figure would be reduced by one-half, which means that each ton of farmyard manure is diminished in value by about 2s. 3d. A steer weighing 7 to 9 cwt., in passing from

the store to the fat condition, during a period of 6 months will increase about 320 lb. in live weight; and this increase will contain about 3 lb. of nitrogen, 2 lb. of phosphoric acid, and $\frac{1}{4}$ lb. of potash. Valuing these substances as before, and similarly assuming an out-put of 6 tons of dung, we find that the theoretical difference in the value of a ton of farmyard manure made in the one case by a milk cow and in the other case by a fattening steer is about 1s. 11d. In actual practice, however, the difference in value will probably be less, because during six months a milk cow will usually consume a larger quantity of nitrogenous food than a steer passing from the store to the fat condition, and the nitrogenous residues in the former case may also be greater.

While the quality of farmyard manure is primarily influenced by the character of the food, it also depends to a large extent upon other causes. Thus, the various farm animals produce manure of differing character and quality, that produced by bovine animals being comparatively wet and dense, so that the mass is not well permeated by air. As a consequence it decays slowly, being what farmers and gardeners call "cold," so that, when applied to the land,

it decays slowly, and therefore its effects are more lasting.

On the other hand, manure produced by horses fed, as they are, on drier food, contains less water, and is not so thoroughly disintegrated; the result being that it is more porous, and being better permeated by air it ferments more rapidly, and is of the character to which the term "hot" is applied. It is, therefore, only manure furnished by stables that is utilized by gardeners as material for imparting heat to a forcing frame. But just because the manure of horses ferments so readily there is a greater risk of loss of nitrogen during the time of storage. That nitrogen is more abundant in the air of a stable than of a cowhouse is evident from the characteristic smell of ammonia which is associated with ill-ventilated stables.

The manure furnished by piggeries rather resembles that produced by bovine animals, though a good deal depends upon the character of the food supplied to the pigs, which, if sloppy in character, produces a cold, low-class manure; whereas if the pigs are getting large quantities of such a substance as pea meal, the resultant manure may be comparatively rich.

Seeing that farmyard manure can seldom be carted direct to the land, it is necessary to provide suitable conditions for storage during a period of three months or more. The objects during this period should be to secure the preservation of the valuable ingredients, to produce equality throughout the mass, and to prevent excessive reduction in weight. To secure these desirable results the following points should be attended to. The floor of the dung heap should, as far as possible, be impervious to the passage of liquids, nor should liquids be allowed to flow away from the mass, unless they can be led into a suitable tank. These liquids contain most of the potash, and also the larger percentage of the nitrogen, and especially of the nitrogen that is more immediately available for the use of crops. One should also see that fermentation proceeds slowly and uniformly, an object that is best secured by keeping the mass as compact as possible, and by maintaining it in a thoroughly moist condition. Compactness can be best secured by making the heap as deep as possible, and by running the barrow, that brings the manure from the various houses, over the heap, so as to assist consolidation. As regards moisture, there will be

least difficulty where storage is done in the open air; but if the rainfall is low, and especially if the manure is stored under cover, it is well to have a tank into which the liquids can drain, and from which they may be periodically pumped and distributed over the mass of manure. Then, again, one should see that the manure from the various buildings—stables, cowhouses, and piggeries—is equally distributed over the heap, so that the dense, moist, cold manure from the cowhouses and piggeries shall have an opportunity of doing something to counteract the tendency towards excessive fermentation that is inseparable from stable dung.

If manure must be used when in a comparatively fresh condition it is well to apply it, where possible, to the heaviest class of land, because such manure can do most to open up the soil, and encourage the circulation of air. If proper conditions of storage have been observed, the loss of weight in three months may amount to no more than 20 per cent.; but during a longer period of storage, and especially in the absence of satisfactory conditions, the loss may amount to quite 50 per cent. While loss of weight cannot be prevented under any circumstances, there should be proportionately

less loss of plant food, and, as a consequence, well-decomposed farmyard manure is relatively richer in nitrogen, phosphoric acid and potash than manure which is comparatively fresh.

Many attempts have been made to create conditions in the manure heap which will prevent undue loss in weight, and at the same time preserve the nitrogen as far as possible. Saturation with liquids is one way of arresting fermentation, and of preventing the escape of nitrogen, but with excessive moisture there is undoubtedly increased danger of loss by drainage. It has also been suggested that superphosphate, gypsum, kainit, and other substances, should be thinly sprinkled over the manure while it lies in the stalls and yards, or as it comes from the various houses, but it cannot be said that experiments in this direction have demonstrated results of much practical value. On the other hand, the spreading of a considerable amount of soil over the heap at frequent intervals, will do something to arrest the loss of ammonia, and prevent excessive decomposition. Good results, also, will attend the use of a certain proportion of moss litter along with straw bedding, the former having greater capacity for the

absorption of liquids, combined with the power to fix ammonia. If a considerable amount of moss litter is employed, the resultant manure will be found to be better adapted for use on light than on strong land, because its power of absorbing and retaining water reacts more beneficially in the former case than in the latter.

In order to save cartage at a busy time of the year it is a common custom in many parts of the country to empty the dungstead once or oftener during winter, and to store the material in temporary heaps in the field. The process of removal from the place of storage at the homestead to the field heap means that the manure is left comparatively loose, so that air enters freely, and volatilization of ammonia, fermentation, and reduction in weight must go on to a greater extent than if no disturbance had taken place. Possibly, also, the temporary heap in the field may be placed upon land that is by no means impervious to the downward passage of liquids, or it may be situated on a slope which encourages the escape of liquids over the surface of the ground. Do what one will, it is impossible to avoid very considerable loss from such temporary storage heaps; and, speaking generally, the practice

should not be resorted to unless obvious advantages are to be obtained. But if it is resolved to empty the dungstead, and to form a temporary heap in the field, one should endeavour to secure in the shortest time as great compactness as possible; and this object is gained most effectively by making what is called a "draw" heap, that is to say a heap over which each load of manure as it arrives from the homestead is drawn or carted. The passage of the carts consolidates the mass in the best possible way, and if subsequently the sloping ends are cut off, and the material thrown on to the top of the heap, much will be done to obviate loss and produce good material. In order further to consolidate the mass and exclude air, it is good practice to throw about a foot of soil on to the top of the mass.

When farmyard manure is carted on to the land for the purpose of being spread, it should not be left to lie for a longer time than is possible in the small heaps that are formed when it is dragged from the cart. The practice that one sometimes sees of leaving these small heaps unspread for days, and even for weeks, cannot be too strongly condemned, for the reason that the liquids drain away and percolate into the soil on

which the heaps rest, with the result that certain spots on the field are over-manured, while the bulk of the field receives a correspondingly smaller amount of fertilizing materials. The loss will necessarily be greatest should much rain fall before the heaps have been spread.

Whenever farmyard manure has been spread over the surface of tillage land it ought to be ploughed in as quickly as possible, because only when it is incorporated with the soil is the loss of ammonia by escape into the atmosphere reduced to a minimum. Moreover, many of the valuable physical effects that dung exerts on the soil cannot operate till the material is ploughed under.

CHAPTER IX

ROTATION OF CROPS

WHENEVER agriculture has advanced beyond primitive conditions one finds farmers alternating different crops on different areas, in place of growing one single crop-species on the same land year after year. The objects and advantages of a rotation of crops may be summarized as follows.

Different crops have different systems of root development ; in some, *e.g.* mangolds, the roots go deep into the soil, while in others, *e.g.* barley, the roots are disposed within comparatively few inches of the surface of the ground. If one were to grow only shallow-rooted crops, practically no use could be made of the plant food lying deep in the subsoil. On the other hand, if one confined one's choice to deep-rooted crops, the plant food present in the surface soil would be insufficiently utilized. But by alternating, either annually or periodically, deep-rooted and shallow-rooted plants the whole body of soil is laid under contribution to provide nourishment, and not only so but plant food drawn from considerable depths by such a crop as mangolds or wheat, will, when the crop is consumed and the residues returned to the land as manure, become available for the use of such a shallow-rooted crop as barley.

While all crops make use of the same kind of plant food, their requirements in the matter of quantity vary within very wide limits. As regards nitrogen, we find that a crop of cereals or of potatoes removes from the land only about 50 lb. per acre, whereas turnips and swedes require twice as much,

and mangolds three times as much of this element. Similarly as regards potash, wheat and barley removing only about 30 lb. per acre, whereas red clover and swedes to give a full yield must have two or three times as much, and turnips about five times as much of this substance. The variations in the requirements of crops for phosphoric acid are not quite so wide as in the case of the two nutritive materials already referred to, but even here we find variations between a minimum of some 20 lb. per acre in the case of potatoes, swedes, red clover, and the cereals generally, and of 50 lb. in the case of the mangold crop. If, therefore, one were to grow only a single crop on any field, one would have to manure very liberally with the particular ingredient that the crop specially affected, and at the same time one would know that materials for which the crop had little use were likely to be going to waste.

It is found that the residues of roots, stubble, and leaves, left in and on a field by the growth of a particular crop, prove excellent plant food for another crop of a different species, whereas one would not often find that these residues sufficed to grow a correspondingly large crop of the

same species as had in the previous year occupied the field. When a crop of red clover is removed from the land, it is found that wheat thrives vigorously upon the decaying roots of the clover; while the leaves of the turnip crop that are left upon the land have a markedly beneficial effect upon a crop of cereals that may follow. If any one doubts the fertilizing value of turnip leaves one has only to look over a cereal crop which has followed a root crop, where the bulbs were topped and where the tops had been left lying in definite rows, instead of being spread equally over the surface of the ground as they should be. Where such spreading has been neglected one will find that the crop is very patchy in growth, being strong and vigorous along the lines which represent rows of tops, but comparatively feeble in the intervals. Crop residues can seldom be utilized as food by a crop of the same species, for the simple reason that many crops refuse to grow in successive years, or even at short intervals, on the same ground. This applies more or less to red clover, turnips, swedes, and beans, though it does not apply to cereals, grass, or mangolds. We have a similar, though not exactly the same, state of things in the case

of sainfoin, for although this perennial plant will grow for several years in succession on the same land, it is found that poor results are got by breaking up the sainfoin ley, and immediately, or even after a short interval of years, seeding down again with sainfoin.

The impossibility of growing certain crops, and the difficulty of growing others in successive years, or at too close intervals, is probably to be traced to more causes than one. But the cause that most frequently interposes a barrier is the presence of disease, the germs of which may linger in the land from one crop to the next, but which can be starved out if the particular host on which they prey is not brought within their reach while they still retain their vitality. Where there is a difficulty in growing the same crop in successive years upon the same land it is frequently said that the land is "sick" to that particular crop. One often hears it said that land is "clover sick" the idea it is intended to convey being that this crop cannot be grown on some particular area until the land has had a rest from the growth of this crop. What the particular disease is that prevents the continuous or frequent growth of this crop has not been fully worked

out, but, at all events, there would appear to be little doubt that some organism—be it a fungus, a bacterium or a stem eel-worm—increases abundantly so long as red clover plants are within its reach, but which can be starved out by taking steps to avoid giving it access to its particular host-plant. Similarly in the case of the cabbage, turnip or swede crops, which, as is only too well known, are preyed upon by a minute fungus that induces cancerous swellings and subsequent decomposition in the roots. This fungus can live only upon cruciferous plants, and although, even in the absence of the plants on which it preys, it can retain its vitality for some years, it is starved out and destroyed if the interval between the crops that it affects is made sufficiently long. Under some circumstances an interval of four years will suffice, but under others a longer period than this must intervene between the growth of two cruciferous crops. In this connection it may also be mentioned that the continuous growth, or the growth at too frequent intervals, of any particular crop may tend to exhaust the land of some necessary element of plant food, and this cause also supplies a reason for cultivating crops under a suitable rotation.

Rotations also provide the opportunity for utilizing both horse and manual labour fully and economically throughout the year, because different crops are sown at different times, and the best times of cultivation and of utilization also vary. Thus, wheat is sown for the most part in autumn; beans to a large extent in the end of February; potatoes, barley, and oats in March and April; mangolds early in May; swedes a little later, and yellow turnips during the month of June. Similarly as regards the harvesting of these and other crops. Red clover is cut about the end of June; cereals for the most part in August; potatoes are largely lifted in September; while mangolds, turnips and swedes are generally got off the land during October, or the early part of November.

The cultivation of crops on a proper rotation also simplifies the preparation of the land for the cultivation of particular crops. Turnips, for instance, generally follow a cereal, which in its turn has followed ley; and it is found possible to secure the fine, tilthy condition of the land, so necessary to the successful growth of the turnip crop, much more easily after a cereal than immediately after ley. Similarly in the case of the

barley crop, which also requires that the land shall be friable and clean, and these conditions are best secured by sowing barley after a root crop which, if properly attended to, leaves the ground free of weeds and in good mechanical condition. With the barley crop is generally also sown the seed of clovers and grasses, and these fine seeds succeed best under much the same conditions as suit the barley crop.

When certain crops, notably cereals, are grown continuously upon the same area, it is found that the land tends to become foul, that is to say weeds become very abundant, and are apt seriously to interfere with the growth of the cereal. This is one of the great difficulties experienced at Rothamsted in the continuous growth of wheat. In actual practice one can, of course, periodically bare-fallow the land, and thus get rid of most of the weeds; but bare-fallows should be avoided as much as possible, and the same object will in most cases be attained by the occasional cultivation of some crop that permits of the land being kept clean during the season of its growth. Crops like turnips, mangolds, and potatoes, which are cultivated in rows two to three feet apart, permit of effective horse and hand hoeing; and if these

operations are attended to, and the season is favourable, the land at the end of the year is left practically free of weeds, the suppression of which is effected, not only by the hoeing, but also by the vigorous growth of the large mass of leaves which characterises these particular crops. Such crops are generally called "cleaning crops," and their presence in a rotation greatly simplifies the solution of practical problems of cultivation.

By growing a variety of crops under a system of rotation one secures a corresponding variety of produce, which comes to maturity, or which can be utilized, at different seasons of the year. As a result, the maintenance of live stock of various kinds is rendered economically possible; and nothing contributes more to the maintenance of the fertility of a holding than the presence of a large head of farm animals. On the American prairies, where wheat is the only crop grown over wide areas, it is practically impossible to maintain any considerable number of farm animals, beyond the horses necessary for the work of the farm. But when the point is reached where the fertility of the holding has been so seriously reduced that profitable crops cannot be grown, it is found necessary either to abandon the

holding, and let it revert to prairie conditions, or to introduce crops other than cereals, so that the maintenance of cattle may become possible.

To the credit of a rational rotation must also be put comparative freedom from the attack of injurious insects. Most of our most destructive insects are very fastidious as regards the diet that they require, and are incapable of living upon any plant but the particular species, or at most genus, that they affect. Thus, for instance, the carrot fly is met with on no other crop; the turnip flea beetle is dependent for its existence upon the presence of cruciferous plants; the mangold fly can only exist in the leaves of beets and mangolds; while the Hessian fly confines its devastations entirely to the Gramineæ, and, one might almost say, entirely to cereals. A few insects are less specialized in their food requirements, as, for instance, the cockchafer grub, the larva of the daddy-long-legs, and the wire-worm. But, speaking generally, the first class contains the majority of our thoroughly destructive insects. In the case, then, of an insect, highly specialized as regards its nutriment, the farmer can do much to hold it in check by depriving it in alternate years,

or over longer periods, of the particular food plant that it requires.

It is a matter of observation that rotations vary in character to a greater or less extent in different parts of the country, and it is also found that even on the same farm the rotation adopted may from time to time undergo modifications. The growing scarcity of agricultural labour has not been without influence in shaping rotations, the tendency where labour is scarce, dear, or inefficient, being in the direction of extending the proportion of land under cereals, and notably under grass. The same result will be reached where a farm is situated inconveniently to markets, because, under these circumstances, there is a disposition on the part of the farmer to increase his head of stock, live animals being marketed at less trouble and expense than dead produce, which requires to be carted to its destination. Then, again, some land takes "kindly" to grass, whereas in the case of other land the production of a satisfactory pasture is a matter of heavy outlay and long delay. If, then, a farmer is dealing with land which can be depended on to graze well under a system of three or four years' ley, he will be encouraged to put more of his land under pasture, than

if good temporary leys are difficult to secure.

In some districts conditions of soil and climate favour the growth of certain crops, or encourage certain systems of stock-keeping. Thus, with a moderate rainfall and heavy soil, the tendency is in the direction of putting a large area of the farm under wheat or beans. In other districts, barley-growing may be attractive, a system of farming which is usually closely associated with the cultivation of turnips. Then, again, the whole system of cropping may be arranged with a view to keeping as large a head of sheep as possible; in another district dairying may be the principal object in view, and this necessitates the growth of large quantities of bulky fodder, and of abundant supplies of green food. The possibility or otherwise of making cleaning crops a regular feature of a rotation, has an important bearing upon the percentage of tillage land that must be bare-fallowed, for if a cleaning crop cannot be depended upon every four or five years, the land must, at some such interval, be left uncropped throughout a season to permit of the eradication of weeds. The occurrence of disease in certain crops often entails drastic modifications of a rotation. For

instance, if cruciferous crops recur upon the same land, even at intervals of four or five years, they are often so affected by the disease of finger-and-toe that it becomes necessary to make arrangements for a much wider interval between consecutive crops of this family. Red clover, too, often presents similar difficulties ; and leguminous crops generally, if they follow each other too closely, are found to contract some form of "sickness," which in ordinary practice can best be circumvented by modifications in the rotation.

The most primitive rotation, if indeed it merits such a term, is that which was practised under the old system of village communities that at one time prevailed in this country, and at a more recent period on the Continent. Under this system the land was annually cropped with wheat, or some other cereal, receiving no manure beyond what was dropped by the flocks and herds which grazed on the stubbles during autumn and early winter. When the produce of the land deteriorated to such an extent as to return little beyond the seed, the cultivated area was abandoned and allowed to revert to weeds, which ultimately formed a rough pasture ; and as nothing was withdrawn

under such management, the land in the course of time regained a certain amount of fertility, and it became possible once more to put it through a course of cropping. One finds this system of agriculture prevalent over large areas of the North American Continent at the present time. In the west of the United States and of Canada, farmers are annually taking wheat crops off the recently reclaimed prairie, no farmyard manure whatever being given, in fact much of the straw is burned in the process of stoking the engine of the thrashing machine that annually visits the holding. For a longer or shorter series of years the crops obtained leave a more or less satisfactory margin of profit, but in the course of time the yield falls to such a low ebb that nothing remains to the cultivator after outgoings have been met. It then becomes necessary either to apply manure to the land or to abandon it. In the older districts of the United States and Canada, where an industrial population has gathered in certain centres, farmers find that it is profitable to maintain stock for the production of meat or milk, and the presence of stock necessarily means the consumption as food and litter of large quantities of straw, with the con-

current production of farmyard manure. Farms which have been adapted to such conditions of management tend to regain fertility, and if artificial manures can also be applied, such land can be profitably farmed indefinitely. But in many parts of the eastern United States one finds wide areas which, at one time under cultivation, are now reverting to forest, the attractions of the virgin land of the West being too great for the farmers who have taken all they can get out of their eastern holdings.

In the Middle Ages, and more recently—in fact, the system is still met with in certain districts of England—large areas of tillage land throughout Europe were managed upon the three-field rotation, or, as the Germans call it, the “Dreifelderwirtschaft,” under which the tillage area was equally divided between a winter cereal (wheat or rye), a spring cereal (barley or oats), and bare fallow. It was an improvement on this system to substitute beans for bare fallow, especially if the bean crop was taken advantage of to practise summer cultivation for the suppression of weeds. As the number of crop-species increased it became possible still further to modify the three-field rotation, which might then take the form of—

1. Wheat, or some other cereal.
2. Beans or clover, or peas.
3. Potatoes, cabbages, turnips, etc.

In some parts of the Cambridge Fens one finds at the present day a three-course rotation, consisting of—

1. Potatoes, mangolds, or mustard.
2. Wheat.
3. Oats.

The introduction into this country, in the first half of the eighteenth century, of the turnip crop led farmers in the east of England to adopt what has come to be known as the Norfolk four-course shift or rotation. This rotation, with its modifications, is now the most important in Britain, and has also been largely adopted in various parts of Europe and America. The Norfolk rotation in its simplest form consists of—

1. Turnips or swedes, partly consumed on the land by sheep, and partly drawn to the homestead for cattle.
2. Barley.
3. Clover.
4. Wheat.

But the rotation is essentially the same if mangolds or potatoes are partly substituted

for turnips, if oats or wheat partly take the place of barley, and if oats replace a certain proportion of wheat. The displacement of one-half of the turnip break by potatoes or mangolds is found to be desirable on land that is much addicted to finger-and-toe, so that, under this modification, instead of any field coming under turnips or swedes once in four years, a cruciferous crop would recur only at intervals of eight years. If care be taken not to reinfect the land by the application of farmyard manure contaminated with the germs of finger-and-toe, the Norfolk four-course rotation, modified as indicated, can be depended upon on most soils to secure sound crops of turnips or swedes. Then, again, if it is found that any particular farm or field shows clover sickness in a pronounced form, it may be necessary, instead of having one-fourth of the tillage area under clover, to be satisfied with only one-eighth; the area of clover so displaced being cultivated with beans, peas, or vetches, crops, namely, of the same natural order as clover, and therefore capable of enriching the land with nitrogen derived from the atmosphere through the action of the minute organisms associated with their roots. So far as combating clover sickness is concerned,

the object would be attained by growing Italian rye-grass, or some other non-leguminous fodder crop; but, of course, under this system the land would not be periodically enriched with nitrogen.

The Norfolk four-course shift has not attained to its present position of importance without resting upon a solid foundation of advantages, cultural and otherwise, which may be summarized as follows: The two principal cereal crops, barley and wheat, are sowed at different times of the year, which is convenient from the point of view of the economical utilization of labour; moreover, they differ in the character of their root-system, barley feeding chiefly on the surface layers of the soil, whereas wheat penetrates deeply into the subsoil. Then, again, it is found that wheat grows well after clover, utilizing very fully the nitrogen stored up in the root-residues, and finding congenial conditions of growth in the compact clover sod. The clover crop, also, being removed from the land not later than July, permits of the ground being ploughed sufficiently early to admit of wheat being sowed at the best time of year—early autumn. It may be mentioned that, if the land is not sufficiently clean, it may be broken up directly the clover

crop is removed, the dry weather of late summer being utilized to cultivate the ground, and to bring the weeds to the surface, most of which will, by such treatment, be killed under the influence of sun and drought. In due course the wheat will be harvested in August, and the stubble, being broken up in autumn or early winter, will be exposed to the ameliorating influence of frost, which is the most effective natural agent in the production of the fine tilth that is so essential to the cultivation of the turnip crop. Turnips conveniently precede barley, which is a cereal crop that can be sowed comparatively late in spring, so that ample time is given for the consumption of a proportion of the turnip crop on the land by sheep. Moreover, the manure left by the folding of sheep remains near the surface after the land has been ploughed with a 6-inch furrow; and such disposition of the sheep droppings admirably suits the shallow-rooted habit of the barley crop. Along with the barley are usually sown the seeds of clover or grass, and these not only find congenial conditions of growth in the clean, well-manured ground, but the resultant plants also grow well during summer under the comparatively mild shade of the barley crop, in other words, barley

is said to be a good "nurse" for "seeds."

Under the Norfolk four-course shift in its simple form one-fourth of the tillage area is under "seeds," as it is called, or, in other words, a one-year's ley, the produce being usually made into hay, though it may be grazed by sheep or other stock. In many parts of the country—notably the north of England and in Scotland, where land takes more kindly to grass, and where stock-rearing is of greater importance—the Norfolk rotation is modified in such a way that, in place of the land being under seeds for one year, it is left down for two. The effect of this modification is that less manual and horse labour is required, and greater facilities are given for stock-keeping. Whereas the first year's ley is usually made into hay, the produce of the second year is almost invariably treated as pasture. Under this rotation—which is specifically known as the Northumberland five-course shift—the ley is generally followed by oats. If wheat is grown at all upon a farm managed on this rotation, it usually comes after the root crop.

In certain parts of the country, notably districts in Scotland where high-farming is

practised, one finds the East Lothian six-course rotation in common vogue. Assuming the tillage land to be divided into six sections, the East Lothian rotation will run as follows :—

1. Turnips or swedes, receiving farmyard manure and artificials.
2. Barley, wheat, or oats, unmanured.
3. Seeds made into hay, receiving artificials, usually about 2 cwt. of nitrate of soda, with or without some superphosphate.
4. Oats, not infrequently top-dressed with about 1 cwt. of nitrate of soda.
5. Potatoes, liberally treated with farmyard manure and artificials.
6. Wheat, unmanured.

Under this system, two-sixths, that is one-third, of the farm is annually dressed with farmyard manure, a condition of things that usually entails the purchase of a certain amount of such fertilizing material, and this assumes convenient proximity to a town or colliery, whence dung can be procured. Besides the third of the farm annually dressed with farmyard manure, probably another third is receiving artificial manure, so that no less than two-thirds of the whole

tillage area is being dressed with fertilizers of one kind or another, a condition of things that fairly merits the term "high farming." It is evident, of course, that this six-course rotation can at once be converted into a rotation of seven years, by leaving down the seeds for two years instead of one.

On very strong land, such as is met with in the Holderness district, a six-course rotation is practised which bears this name, and may be set out as follows :—

1. Turnips, swedes, cabbages, or mangolds.
2. Wheat.
3. Beans or clover.
4. Wheat.
5. Clover or beans, the beans being put on land previously under clover and the clover on land previously under beans.
6. Wheat.

With the exception of the turnips these crops are all strong-land crops, and it will be seen that three-sixths, that is, one-half, of the farm is annually under wheat, while other two-sixths is under a nitrogen-collecting, *i.e.* a leguminous, crop.

On the strong carse land of central Scotland the following eight-course is not unusual :—

1. Bare fallow.
2. Wheat.
3. Beans.
4. Wheat.
5. Turnips.
6. Barley.
7. Seeds hay.
8. Oats.

Here, as under the Norfolk four-course shift, one-half of the farm is annually under a cereal crop, and one-fourth under a leguminous crop, assuming that the seeds hay is principally red clover. On the other hand, only one-eighth of the farm is under turnips, this crop being rather uncertain and difficult to grow on the strongest classes of land.

On a strong-land farm where dairying is practised, and where, consequently, every effort must be made to secure a root crop, turnips or swedes are frequently grown after bare fallow, a system that permits of the production of the finest tilth that can be secured. Dung having been spread in the drills in autumn, the land is ridged up and left lying fully exposed to the frosts of winter, and in the month of May, after artificial manures have been sowed broadcast over the ground, the ridging plough is run

between the drills to collect all the fine mould along the lines where the turnip seed is distributed.

In the east of England, notably Norfolk, Suffolk, and Cambridgeshire, where the highest quality of barley is grown, the Norfolk four-course shift is modified as follows :—

1. Roots.
2. Wheat.
3. Barley.
4. Seeds.
5. Oats, or wheat.

Here barley follows wheat, as it is found that in this way malting barley of the highest quality can be secured, although at the cost of some reduction in quantity. If barley immediately follows roots, especially if folded by sheep, it frequently obtains more nitrogen from the manurial residues than is consistent with the production of grain of the highest class. What the maltster wants in barley is a high percentage of starch, with as little proteid or nitrogenous substance as possible. The introduction of wheat between roots and barley reduces the nitrogen contents of the soil, so that the barley that follows yields grain of a starchy, as opposed to a “flinty,” character.

In parts of the country where the potato crop is of special importance, a rotation is selected which will permit of a large proportion of the farm being put under this crop. If the farmer is satisfied with one-fifth of his total tillage area under potatoes, he can select the Norfolk four-course shift and introduce potatoes between seeds and wheat, thereby converting a four-course into a five-course rotation. Potatoes are found to grow well after a one-year's ley, but if one-fifth of the farm is not considered sufficient for the potato crop, part or all of the "break" that would, under ordinary circumstances, be devoted to turnips or mangolds can also be placed under potatoes. If all the root break were given over to potatoes, it would mean that a farm worked upon such a five-course rotation would show two-fifths of the whole under this crop.

It is in districts where the climate, soil, and system of farming encourage the cultivation of catch-crops that the planning of a rotation requires most attention. On the extensive tracts of Down land in the south and east of England, where sheep-breeding is the mainstay of farming, the system of cropping is primarily arranged to provide a continuous supply of suitable green food

for the sheep flocks during the greater part of the year. During winter, turnips and swedes are chiefly depended on, followed by winter rye, winter barley, winter vetches, kale, rape, and crimson clover, to be consumed throughout March, April, and May. During the consumption of the crimson clover and rye, the sheep are often allowed a certain quantity of mangolds, which are either cut and placed in troughs, or are thrown down whole in the daily fold. By the time these crops are consumed, ordinary clover and seeds' mixtures are ready for folding, or the flock is turned out to graze in the open field or upon the Down. About the month of July the aftermath of the clover is ready to be folded, to be followed later by mustard and early turnips. Rape is a great stand-by in Down farming, it being consumed either in autumn or spring, when, often in conjunction with thousand-headed kale, it gives a large quantity of succulent food.

The yields of some of the crops mentioned are, in the districts indicated, too small to make it profitable for the farmer to devote a whole year to the growth of the crop concerned. He must therefore endeavour to grow such a folding crop as mustard, crimson

clover, or winter rye, between two principal crops of the farm, hence the origin of the expression "catch crop." In the north of England, and throughout Scotland, the climate seldom admits of catch cropping, though in some of the better districts of Scotland one finds farmers sowing Italian rye-grass after an early crop of potatoes, the grass being removed by the end of May or beginning of June in the following year, in time to permit of its being followed by a crop of turnips. Sometimes also a farmer is able to harvest his crop of red clover before the end of June, and if he is very expeditious he may succeed in getting the ground ploughed and sufficiently cultivated to permit of the sowing of a crop of white turnips. In the north, turnip seed is not infrequently grown as a catch crop after clover, early potatoes, or Italian rye-grass. The seed is ripe about the end of May, and, if sowed before the beginning of July, sufficiently robust plants will be produced to withstand the winter. In the following year the plants shoot out to produce seed, which is harvested, as has already been said, about the end of May, to be followed by Italian rye-grass, or some such crop.

It is, however, in the warmer and drier

districts of England that catch cropping finds its greatest development. Not only must the climate be good, but the soil must be fairly light, so that there is no difficulty in securing a good seed-bed in the minimum of time after a crop has been removed from the land. Strong land makes catch cropping practically impossible, it being difficult to plough such land during dry weather at the height of summer. Even if it be broken up at great expenditure on horse labour, or through the utilization of steam, the furrow is so rough and intractable as to be incapable of yielding a satisfactory seed-bed, without the intervention of a long period of exposure to sun and air. But it is of the essence of success in catch cropping that no time should be lost between the separation of one crop from the land and the sowing of the next, and this is only possible where the land is of such a character as to permit of its being ploughed and otherwise worked under practically any conditions of weather.

By way of illustrating the practice of catch cropping we may take the following rotation. Wheat having been harvested and cleared from the land by the middle of August, the stubble is immediately scarified, either by horse or steam power, so that

most of the weeds are dragged to the surface and destroyed. In this way an excellent seed-bed is prepared for the broadcast sowing of crimson clover or stubble turnips, the former furnishing valuable folding food in the following spring, while the turnips can be utilized at any time during winter. Or the wheat stubble may be ploughed with a shallow furrow and sowed with white mustard, which in six weeks will be ready for folding, and is largely used in the south of England for "flushing" the ewe flock during the month of October. In the mildest districts rape may be sowed instead of mustard; and when the weather becomes genial, about the beginning of March, the plants shoot out rapidly, to furnish a large yield of useful sheep "keep." Whatever the crop selected to follow wheat, it must be cleared from the land not later than the middle of June, and in many cases the ground is cleared considerably earlier. When the catch crop has been utilized the land is at once ploughed and suitably dressed with artificial manure, perhaps even with farm-yard manure; and mangolds, swedes, or yellow turnips are sowed. Mangolds are sowed in the south at much the same time of the year as in the north, namely early in

May, but in the south swedes and common turnips are not put into the land for a month or six weeks after the time at which they are sowed in the north of England and throughout Scotland. This fact explains, to some extent, the greater ease with which catch cropping may be practised in the south as compared with the north, though the harder winters of the north are the main restricting cause. There is not much chance of getting a catch crop in between the mangolds, swedes, or turnips, and the barley or other cereal that follows; nor is there the opportunity of catch cropping immediately after barley, because that crop is usually sowed down with "seeds." In a season of drought, however, when the "seeds" fail, the barley stubble may be broken up, as in the case of the wheat stubble, and similar crops may be made to follow. As regards the "seeds," a catch crop may or may not follow, according to circumstances. If the clover stubble is broken up by the end of June it is possible to cultivate at least one crop of mustard before the time for sowing wheat, which is the crop that generally succeeds "seeds." In place of treating the clover stubble in this way, it may be ploughed and, as it is called, "bastard fallowed"—that is to say, left

uncropped, with occasional harrowings and grubblings—during the warm, dry weather of late summer, when weeds will be killed by heat and drought, and the land mellowing under the influence of the weather. When land is treated in this way it is finally ploughed in September, so that wheat is sowed in good time in the end of that month or throughout October.

It is sometimes recommended that catch crops should be grown in order that they may subsequently be ploughed into the land to increase the stock of humus. There is no doubt that such treatment has considerable effect upon the fertility of the land, but it is probable that, on the whole, greater advantage accrues to the farmer through the consumption of the catch crop by stock. Theoretically a leguminous crop should be most valuable for green manure, but, as has already been pointed out, better results often follow the use of white mustard.

CHAPTER X

SEED

To secure success in tillage farming, no little attention must be given to considerations of seed. If one is using home-grown supplies, one may have to be satisfied with seed that would not make a very attractive market sample, or which does not show very high power of germination. Seed produced on the farm is not valued at so high a rate as seed that is imported, so that one can afford to sow somewhat thicker, and thus make up for impurities such as chaff, husks and grit; but only under rare circumstances would one be justified in using any seed whose impurities were weeds. One of these rare exceptions would occur where poor foul land was being seeded, for with weeds naturally present in practically unlimited quantity, the addition of a few more can make very little difference. If, however, one is purchasing seed, one should take purity, cleanness, and germinative capacity into serious account. As regards purity, it is evident that a purchaser wants to be sure of obtaining the particular species or variety of plant that

he desires. In some cases it is not difficult to determine whether a sample or consignment of seed is true to name, but in other cases one must rely upon the character of the vendor for careful business methods and upright dealing, or one has to wait until the resulting plants have grown sufficiently to disclose their identity. It is, of course, a simple matter to distinguish the seed of barley from that of oats, or the seed of ryegrass from that of Timothy; but it is not so easy to distinguish rape seed from swede seed; while it is practically impossible to detect any difference between the seed of varieties of swedes, or between Broad Red Clover and Cow Grass. Mistakes on the part of sellers have occasionally led to expensive arbitration or litigation, as, for instance, where two-cut sainfoin has been supplied for the single-cut variety, or where rape seed has been inadvertently supplied to a purchaser of swede seed.

Purity is concerned not only with the question of differentiation between closely related varieties, but also with freedom from the seeds of indifferent or positively injurious plants. Apart from the case where a sample contains the spores of a destructive fungus like Smut, one may meet, in a seed sample,

with the seeds of such a pest as Dodder, a parasitic plant of the natural order Convolvulaceæ, which by attaching itself to clover, flax, and certain other cultivated plants, is capable of doing a large amount of harm. Or the impurity may take the form of weed seed, such as Twitch, Bindweed, Sorrel, and many others. Such an impurity is objectionable on many grounds, not only because the higher the percentage of impurity the less the percentage of the seed that one desires to purchase, but also because, through the agency of such impurities, weeds may be introduced to land hitherto clean. The question of impurities is of least importance where the seed is to be used upon land that is by no means clean, and becomes of the highest importance where one is cultivating land as free from weeds as it is possible to secure.

Cleanness, as apart from purity of species, means the absence of chaff, empty husks, grit, sand, and the like ; and while such substances are not positively harmful, their presence in a sample necessarily depresses the percentage of the seed which one desires to sow.

In purchasing seed of all kinds, one should as a rule accept only that which is of high germinative capacity. This is a property

that varies greatly in the seed of different species, some, like cereals, turnips, swedes, and clover, usually germinating within a fraction of 100 per cent., while others, such as the smaller grass seeds, frequently fail to germinate over 80 per cent. Other things being equal, seed of high germinating power is usually cheapest, because a less quantity is required, and the resulting plants are usually stronger and more vigorous. A sample of seed of low germinative capacity is usually in this condition either because it is immature—that is to say, is insufficiently ripened—or because it is old—that is to say, not of the immediately preceding crop—or because it has “heated” in the stack, or at some other stage of its history. One will always find in the case of a poor sample, that many of the seeds that germinate produce plants so feeble as to be unable to survive the first few weeks, or it may be days, of the conditions that they meet with on an ordinary farm or garden. It is evident, therefore, that a laboratory test, conducted as it is under conditions specially favourable to germination, and stopping at the point where sprouting occurs, supplies figures that unduly favour poor seed.

The “Real Value” of a sample of seed is

got by regarding both the purity (including cleanness) and germinative capacity, and is usually stated in the form of a percentage. Suppose, for example, that a sample of cocksfoot seed germinates 90 per cent. and has a purity of 90 per cent., the Real Value—that is to say, the number of seeds in 100 that are both true to name and capable of germinating—is obtained by multiplying 90 by 90, and dividing by 100, which gives 81. Or, to take another case, if the purity is 90 and the germinative capacity 70 per cent., the Real Value works out at 63. Suppose that in the case of the sample having a Real Value of 81 the price is 1s. per lb., the value of the other will be got by multiplying 12d. by 63 and dividing by 81, which gives a figure of practically 9¼d. This is really more than the inferior sample is worth, for the reason already given, namely, that where the germinative capacity is low, many seeds which would count in a test of germination are of no practical value.

Most farmers must annually purchase seeds of one kind or another. Speaking generally, farmers do not raise their own grass seed, turnip and swede seed, mangold seed, clover seed, and the like; therefore, for such seeds a farmer has usually no

alternative but to go into the market and purchase. In respect of this, however, custom differs in different parts of the country; for whereas it is rare to find English farmers growing ryegrass for seed, it is almost the rule in many parts of Wales, in the north of Ireland, and in the south-west of Scotland. Again, as regards turnip and swede seed, one finds in the north-east of Scotland that most farmers annually select a number of their best bulbs, and plant them out on some spare piece of ground, in order to supply themselves with home-grown seed. The growth of turnip seed requires some little care and the exercise of some intelligence, for the bulbs have to be selected with discrimination, and have to be grown at a distance from other cruciferous plants in flower, by whose pollen they might be contaminated. Then, at the season when the seed is approaching maturity, the plants, must be scrupulously protected against sparrows, finches, and similar seed-eating birds, which seem to be willing to run any risk for a meal of turnip seed. The growth of clover seed is even more restricted than that of rye grass and turnips, the crop being cultivated for seed practically only in the warmest and driest parts of England and Ireland.

Apart from cases where farmers, not having home-grown seed, must go into the market and purchase, many circumstances may arise to make it desirable that a farmer shall import seed to his holding, even where he has supplies of the same species, and even of the same variety. From time to time seed-growers or importers place varieties on the market which possess specially desirable characters, such as productiveness, early ripening, good standing power, etc., and it may pay a farmer to sell seed which he would otherwise use, and to purchase a new strain of the same variety.

Then, again, it is found from experience that seed from a different soil, or a different climate, produces plants of greater vigour than is displayed by crops of the same variety which has long been grown on the same holding or in the same district. In the case of certain plants and animals a change of soil and climate seems to impart a vital impulse that at once arrests attention. The cause may be obscure, but the result seems to be illustrated in the wonderful productiveness of rabbits in Australia, in the great size of trout in New Zealand, in the extraordinary vigour of English thistles on the pampas of South America, in the aggressiveness of Canadian

pondweed in some British lakes, and in the way in which European weeds have monopolized the pollution of Canadian fields. It is found in the case of cereals that if seed be obtained for a backward farm from a much earlier district, the crop grown during the first year or two ripens earlier, and furnishes a "brighter" sample than the same variety which has all along grown in the particular district.

Generally speaking, farmers import seed from a dry climate to one that is moist, and not *vice versa* ; and such practice appears to be based upon sound physiological grounds. A variety that has long grown in a district of low rainfall, and with relatively dry air, has adapted itself to make the most out of such conditions. The cuticle, epidermis, and stomata of its leaves have developed in such a way as to retard expiration of water, with the result that it can flourish luxuriantly even when soil-moisture is not abundant, or where the conditions encourage excessive evaporation. These peculiarities are carried in the embryos when the seed is transferred to a new district, and even if the quantity of moisture in the soil and air there be much greater, the resultant plants seem capable of rapid adjustment to the new conditions,

and show successful growth. On the other hand, a variety that has grown for years in a wet climate exhibits modifications of the leaf tissue, and develops a different type of stoma, and if the variety, so modified, be moved to a dry district, it seems to be incapable of placing itself sufficiently quickly in harmony with the new environment to show immediately vigorous growth, though this may come with years of adaptation. On the contrary, it continues to transpire large quantities of water, which, though not excessive where supplies are abundant, must be so designated where supplies are restricted.

Sometimes a farmer is forced to purchase seed, by reason of the fact that his home-grown supplies are much contaminated by impurities. On some farms, for instance, wild oats are so abundant that home-grown grain cannot be used as seed.

The case of seed potatoes is not quite on all-fours with those just indicated, because the potato crop, as the term is ordinarily used, is not grown from seed but from cuttings; propagation, in the agricultural and horticultural sense, being directly comparable with the raising of poplars, willows, gooseberries, and currants, from cuttings,

or of apples and pears by grafting. Such a method of increase is called vegetative, as opposed to propagation by means of seed, which is defined as sexual reproduction. In the case of the potato, what appears to determine the health of the crop, and a large yield, is strong development of the corky layer which envelops the tuber, and of the epidermis and cuticle of the leaf and stem. If these protective coverings are thick, the plant is able to offer successful resistance, more or less complete, to the attack of the many parasites that prey upon it. In inclement districts there is a tendency on the part of all plants, including potatoes, to develop a thick skin as a protection against the severe conditions of the environment; and when such thick-skinned tubers are subsequently planted in a district with a better climate, they still, for some years, retain their acquired characters, with consequent comparative immunity from disease. It is possible, also, that tubers being less fully matured in a late district, sprout more vigorously when used as "seed." But, whatever the reason, it is at all events the practice for growers, in the best potato districts, such as East Lothian, Lincolnshire, Bedfordshire, and Cambridgeshire, to import

their seed potatoes from Scotland and Ireland ; Jersey, for instance, taking considerable quantities from the Isle of Skye.

Perhaps there is no crop on the farm for which a farmer goes more frequently into the market for "seed" than potatoes. Not only is the yield found to be increased by obtaining fresh seed from a more inclement district, but new varieties are constantly being put on the market which are distinguished for some desirable property—prolificness, resistance to disease, etc.—and enterprising potato growers naturally desire to make trial of such new sorts. It is found that in the course of time, varieties, which in the early years of their existence were practically immune from disease, lose their constitutional vigour, and are no more resistant than those that they supplanted. When this stage has been reached, the necessity for a change of seed becomes pressing, so that from one consideration and another potato growers are constantly on the market for fresh seed. Twenty years or so ago the varieties that held the field were the "Champion," "Bruce," "Prince Regent," etc.; and, more recently, "Up-to-date," "Farmer's Glory," "Factor," "Abundance," and others, have enjoyed a high reputation,

no doubt, like their predecessors, ultimately to give way before newer varieties.

New varieties of potatoes are all obtained by raising seedlings, which are either got by the indiscriminate sowing of the seed of the berries, or are the result of the definite crossing of distinct varieties. Most of the seedlings are no improvement on their parents ; but, by careful selection, a certain proportion showing desirable features may be separated out, and when these have been vegetatively propagated in sufficient quantity they are distributed through the ordinary trade channels.

Not only have certain varieties of potato exceptional powers of disease resistance, but the same is also true of other plants, such as wheat ; Rivet or Cone, for instance, being much more resistant to rust than others, such as Michigan Bronze. From time to time, also, varieties of turnip with marked powers of resistance to the attack of finger-and-toe are put on the market ; and similarly in the case of gooseberries (resistance to American Mildew), apples (resistance to canker), etc.

Many individuals and commercial firms are engaged in this and other countries in attempting to improve existing varieties of

crops through the agency of seed, that is, by breeding. While many of the varieties so produced are hardly an improvement upon their predecessors, there is no doubt that many notable successes have been scored, and on the whole the character of our farm crops, and, it may be added, of our farm animals, has undergone great improvement during the past fifty years. The improvement of plants by breeding takes two lines, improvement by selection, and improvement by crossing or hybridization, and as a rule both of these lines are followed in arriving at the final product. In attempting to improve plants by selection, one takes such opportunities as present themselves of collecting the seed of those individual plants which show in a marked degree the qualities that one desires to see in the progeny. By collecting seed from a number of individuals one does not obtain a pure strain, although the crop in bulk may have desirable characteristics. To obtain a pure foundation stock one must start with the seed of a single plant, sometimes even with a single grain, and although this method of procedure is slower to furnish results, it is probably more satisfactory in the end. Of course, even where one selects seed from a

large number of individual plants, one can obtain a pure foundation stock from the best single plant that results from sowing the mixed seed.

What the characters shall be that the plant breeder fixes his attention on, must depend on circumstances. Even within the limits of a single plant-species, such as wheat, one has many characteristics to choose from, such as yield, freedom from rust, strength and length of straw, presence or absence of awns, colour and hardness of grain, colour of husk, time of maturing, tillering, resistance to weather, and others. In breeding turnips, kohl-rabi, swedes, and mangolds, the object that one principally desires to secure, besides a large yield and good keeping properties, is a high percentage of sugar, because it is chiefly this substance in the crops indicated that determines their feeding properties. On the other hand, what one wants to secure in potatoes, besides yield and freedom from disease, is a high percentage of starch, for on this constituent depends the desirable culinary property of mealiness. On the Continent, where enormous quantities of potatoes are distilled for the production of spirit, a high percentage of starch is even more important than in this country. In

the case of barley it is starch also that is all-important, because it is this substance which, when treated on the malting floor, changes into maltose; and this, when fermented, determines the quantity and quality of the product of breweries and distilleries.

Having secured a foundation stock of individual plants which show the desired characters, one proceeds to cultivate them year after year, being careful to eliminate and destroy any individuals which show undesirable variations, or which tend to hark back to the original strain. On the other hand, one retains the seed of such plants as display the characters that are considered desirable, and so, in the course of time, by the process of elimination and selection, one obtains a large supply of seed of some new and improved variety of crop. In the case of wheat, barley, and oats, which are self-fertilizing, one will find practically no tendency to vary, if one sows only the seed of a single individual plant, and if no artificial cross-fertilization has been performed. Selection, therefore, is of importance, in the case of these plants, only in securing the parent type.

Improvement by selection depends primarily upon a property in plants and animals

called variation, which means that although the progeny resemble the parents, the resemblance is never quite complete. Without variation there can be no improvement. Variation may mean much or little, it may imply some small divergence from the original type, which is so inconspicuous as to be impossible or difficult of detection; or it may mean a sharp departure from the original type, in which case it may merit the term "mutation" or "sport." Sports may instantly give rise to a new breed, whereas, in the method of improvement by selection throughout a series of generations the breed is secured slowly and with more difficulty. Animals more than plants frequently show a tendency to reversion or atavism, which means that the organism is reproducing certain characters possessed by an ancestor, but not by an immediate parent. The ancestor may be no further back than two or three generations, or it may be much more remote.

In the practice of breeding, no matter which line is adopted, one must see that the individual plants one propagates from year to year are given precisely similar conditions of growth, because it is only by attending to this matter that one can be sure that

robustness, or the opposite, in individuals is due to inherent qualities, and not to the influence of the environment, in the widest sense of the term.

It was chiefly by methods of selection that the old breeders, such as Le Couteur, Chevalier, Hallet, Lawson, Shirreff, and others, secured the results that have made their names famous. At the present time simple selection is still followed with good results, but better and more rapid results often attend selection that has been preceded by crossing. For example, one may take two individual plants of a species, such as wheat or oats, that usually shows self-fertilization, and, with the adoption of precautionary measures that need not be gone into here, one transfers the pollen of one plant to the stigma of the other, and, if fertilization has succeeded, one obtains a cross which combines in it, latent or conspicuous, the characters of its parents. It is found that plants raised from seed that has been thus secured are much more liable to vary than is the case with plants resulting from self-fertilization. When one has, by this means, fostered the tendency to vary, one is given the opportunity of a much wider range of selection than would otherwise have been possible, and thus improvement begun

by crossing is completed by selection. It is found that even the crossing at random of different types often gives fairly good results, though greater success is secured by the union of types which display in a marked degree the characteristics that one desires. The best results of all, however, are obtained by careful selection continued throughout some years, until one has obtained a pure stock, followed by the mating of distinct individuals, the completion of the improvement and the fixing of the type being subsequently effected by the process of selection and elimination. By starting in this way it is found that there is much less tendency to reversion to undesirable characters.

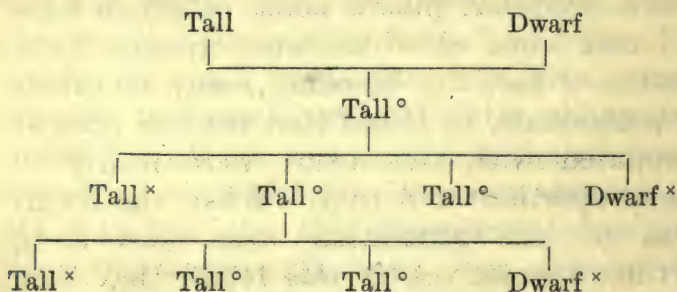
When one mates two individuals possessing special characters, these characters may be so intimately blended in the progeny that it is impossible to say that the peculiarities of one parent are more conspicuous than those of the other. On the other hand, it very frequently happens that the offspring shows the characters of one parent only, those of the other being latent, although they are capable of displaying themselves in subsequent generations. The term applied to this condition of things is prepotency, which

may be conspicuous without being exclusive, but may also be so assertive as to be absolute. Then, again, when the characters of the parents are reproduced in the offspring they may be equally intermingled, or they may appear in patches. In cattle the former condition of things, so far as hair colour is concerned, is illustrated in blue-grey Short-horn-Angus or Shorthorn-Galloway calves, where the whiteness of the father and the blackness of the mother reappear as black and white hairs which occur equally all over the animal's body. The other condition of things—inheritance of colour in patches—is illustrated by the piebald, where the black and white colours are separated in distinct areas. This result is called particulate inheritance, and amongst plants is best illustrated by that curious hybrid laburnum, *Cytisus Adami*, which is a cross between the ordinary laburnum with yellow flowers, and another laburnum whose flowers are purple. In *Cytisus Adami* we find flowers in whose petals the colours of both parents are blended; but we have also, on the same plant, yellow flowers, which are indistinguishable from those of the common laburnum, and purple flowers, of precisely the same colour as those of the purple parent.

During the last ten years much of the work of plant breeding has followed what are called Mendelian lines. The name is derived from an Austrian monk who, about the middle of last century, occupied his leisure with plant breeding, and although his results appeared in a local publication, it is only of late years that they have attracted much attention. Hitherto plant and animal improvement by crossing has been slow to furnish stable strains, for the reason that one has never been sure how to select from the progeny those individuals that were of a fixed type, and would therefore breed true. Mendel, however, showed that the characters of the parents are transmitted to the offspring according to a definite law, now known as Mendel's law, by the observance of which very striking results have been secured in a remarkably short space of time. The law, no doubt, appears to break down at many points, but this is probably due in most, if not in all, cases to the fact that the parents are not "pure-bred," in the strict sense of the term. Mendel's experiments were carried out with peas, some plants of which he found to possess the character of tallness as contrasted with dwarfness, greenness in the seed as compared with yellowness, wrinkled seed

in place of smooth seed, and purple flowers in place of white. For the purposes of illustrating his law we may take the characters of tallness and dwarfness. Mendel found, when he mated a tall pea with a dwarf pea, that the seed so produced grew plants which were all tall, and, so far as external appearances went, it was impossible to tell any difference between the various individuals. When he allowed these tall peas to fertilize themselves, he secured seeds which produced plants, some of which were tall and some of which were dwarf. As a matter of fact, by breeding many hundreds of individuals, he found that the tall peas as compared with the dwarf were nearly in the proportion of 3 to 1. When the dwarf peas of this generation were allowed to fertilize themselves, it was found that they all bred true, showing no disposition whatever to revert to the tall type, and this purity of breeding was found to continue through successive generations. As regards the tall peas of the second generation, however, Mendel found that whereas a certain number of them could be depended on to give seed that would only produce tall individuals, the larger number of the tall peas of the second generation yielded seed that

produced plants partly tall and partly dwarf. As in the second generation so in this—the third—these dwarf individuals could be depended on to breed true to type, a condition of things that was continued throughout an indefinite number of subsequent generations. But the tall peas of the third generation did not all transmit their character throughout the following generations, only some possessing this power. The results can be best set forth in such a diagram as is here inserted.



x = Will breed true.

° = Will not breed true.

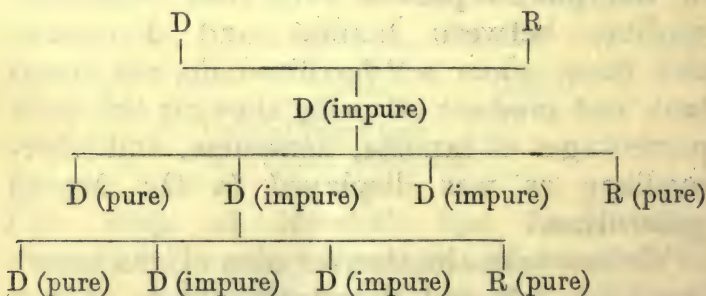
This work of Mendel's has been fully confirmed by other investigators, so that it may be confidently predicted that tall and dwarf peas, if bred together in sufficient numbers, will produce similar results in the generations that follow.

Of late years Mendel's law has been applied

with great success to the breeding of wheat, and as an example of the applications of his law we may take the crossing of two wheats, the one possessing a lax ear, and the other an ear that is dense. When such wheats are interbred they produce an offspring whose ear stands intermediate between the characters of the two parents, that is to say, it illustrates the law of blended inheritance. When the individuals of this first generation, showing intermediate characters, are allowed to exercise self-fertilization, it is found that in the next generation 25 per cent. of the plants possess lax ears and will breed true, that other 25 per cent. possess dense ears and will also breed true, whereas 50 per cent. of the plants possess ears that are intermediate between laxness and denseness, and these when self-fertilized do not breed true, but produce offspring showing the same percentages of laxness, denseness, and intermediacy as was displayed in the second generation.

We can take the simpler case of pea breeding from tall and dwarf parents to give a general illustration of the law. The character—in this case, dwarfness—that comes out in the second generation in individuals that breed true, and which was masked or obscured

in the first generation, is called a “recessive” character; whereas the character which was exclusively present in the first generation, and which was also displayed by 75 per cent. of the individuals in the second generation, is called the “dominant” character. The general law may be expressed by means of such a diagram as is here inserted, where D stands for a dominant character, and R for a recessive. Plants possessing the recessive character, if self-fertilized, all breed true, whereas of the plants in the second generation that possess the dominant character only one-third breed true, two-thirds breaking up in the proportion of three dominants to one recessive.



It may be asked : If in the second generation we get pure recessives and a certain proportion of pure dominants, what is the advantage of crossing as compared with sticking to the

original parents? There are many advantages, but one obvious one is that the parent possessing a dominant character may also possess another desirable character that the recessive parent has not got, and it is thus possible ultimately to raise a strain possessing not only the recessive character, but also the desirable character of the original dominant parent.

It has not been possible to classify all plant characters into the two groups of "dominant" and "recessive," but sufficient work has been done to enable us to state with confidence that the following characters are dominant: in the case of peas, tallness, round and green seed coat, yellow colour of the material (cotyledons) within the seed coat, and purple colour in the flowers; whereas the opposite characters, namely, dwarfness, wrinkled seeds, white or yellow seed coat, green cotyledons, and white flowers are recessive. In the case of wheat the absence of awns (beardless), lateness of ripening, and sensitiveness to rust are dominant; while the presence of awns (bearded), early ripening, and immunity from rust are recessive characters.

Having indicated circumstances under which it is desirable and may be necessary to change seed, a few words may be added with

regard to other considerations that should be weighed before committing the seed to the land. In some parts of the country one finds that a particular variety of crop is invariably sowed broadcast, while in another district the common practice may be to sow it in rows or, as it is commonly called, to drill it. The advantages and disadvantages of these two methods of seed distribution, and the special circumstances to which each is applicable, may be shortly discussed.

When seed is distributed by a properly constructed drill that is adjusted satisfactorily, the grains are not only all covered with soil but all are covered to a proper depth. In broadcasting, on the other hand, a certain amount of seed will fall between clods or between the furrows and be buried too deep, while a certain amount will probably remain on the surface of the ground, and not be buried at all. The latter, if it escapes the attention of birds, may not germinate, or if it does produce plants these may be destroyed by drought before they have secured a proper root-hold. With regard to the seed that is buried too deep, it may be deprived of the air that is an essential condition to germination, or it may be in such a cold stratum of soil that germination is retarded ; and when

it does produce plants these may have a difficulty in reaching the surface of the ground, owing to the mechanical resistance of the soil, or because the reserves of plant food stored up in the seed are insufficient to maintain the plant until it has reached the surface, and unfolded its leaves to the influence of air and sun, and has begun to assimilate fresh supplies of food. The actual depth at which seed should be deposited varies with soil, and with the character of the seed itself. Light soil, being better aerated and less resistant to the upward progress of the young seedling, can be placed over seed to a greater depth than clay soil. As regards the relationship of seed to soil covering, it may be said that, in general, the smaller the seed the shallower should be the covering, and the larger the seed the greater the amount of soil that may be spread over it. Beans, for instance, will easily reach the surface of the ground through three or four inches of soil, wheat may be buried to a depth of two inches, turnip seed is best covered with about one inch of soil, whereas many of the smaller grass and clover seeds can scarcely produce plants if they are buried under more than about half an inch of soil.

When seed is drilled all the resulting plants have an equal amount of growing space. It is true that in the direction of the row the plants are much crowded, but all have equal opportunities of spreading their roots into the space between the adjoining drills. On the other hand, where seed is broadcast it can never be distributed with such equality as to secure equal growing space to all the plants. In this respect, however, a good deal depends upon the skill of the sower, if hand distribution is practised, or upon the efficiency of the machine, if broadcasting is done by horse labour, but more depends, as a rule, upon the character of the surface of the ground. If the land has been well ploughed, the conditions will be most favourable to equal distribution; on the other hand, with irregular furrows, the seeding may be very patchy. One great advantage of drilling crops as contrasted with broadcasting is that the former admits of hand and horse hoeing, while the latter does not, or only imperfectly; and on land that is much affected by perennial weeds, like twitch, or annual weeds, like charlock, drilling is of special importance. It is also found that less seed is required when it is drilled, chiefly because one can be more

certain that all the seeds are distributed at such a depth as to secure the best conditions of germination and growth. Whereas 3-4 bushels of wheat per acre are necessary where the seed is broadcast, it seldom happens that more than 2-2½ bushels are used under a system of drilling. It is found that cereal crops which have been drilled are less liable, as the harvest approaches, to be laid by heavy rain or strong wind, than is the case with broadcast crops. This is probably due to the fact that where the plants stand in regular rows the sun is better able to get at the lower parts of the stems, and, as sunlight encourages lignification, such straw is stronger and therefore less liable to be beaten down by rain or wind. This consideration has greatest importance in the case of a variety of cereal which produces a large bulk of straw, or which produces straw that is known to be feeble. It is also evident that the matter is of special importance in the case of rich land, where "lodging" is most liable to occur.

While birds may pick up a certain proportion of broadcast seed which is left exposed on the surface of the ground, it is probable that, on the whole, birds, and especially rooks, do greater damage to drilled

crops than to those that are broadcast. In the latter case they have, as it were, to search for every individual grain, whereas, when the grains are sowed in definite rows, birds seem to learn the art of running their beaks up the rows, and thus of securing rapidly a large percentage of grain. It may be added, in considering the advantages and disadvantages of the two systems, that drilling crops is the more costly operation, for whereas in broadcasting it is possible to do good work by hand or, with a simple and cheap machine, drilling entails the use of a somewhat expensive machine, and one which requires more horse and manual labour, and covers a much smaller area in the day.

Before proceeding to sow, one ought also to consider the question of density of stocking. It is not the individual plant that we want to favour but the whole community, and, according to circumstances, this end will be secured by having due regard to the amount of seed that should be employed. Other things being equal, we would sow less seed on good soil than on poor, for the reason that in the former case we may expect each plant to grow more vigorously and to reach a larger size. It is also found that

tillering—that is, the production of several stems by one plant—is most associated with fertile soil. Then, again, the variety is not without influence upon the quantity of seed required. Some varieties of cereal tiller more than others, and consequently less seed may be used in their case. Speaking generally, it is found that while many of the new varieties of oats give a large yield, they show no great disposition to tiller, and, therefore, must be sowed 20–50 per cent. more thickly. Again, one would sow more thickly in a poor than in a good climate, because in the former the individual plants are less vigorous, and there is a greater percentage of loss amongst the seedlings in their earlier stages of growth. One finds, for instance, that in the more backward districts of Scotland oats are generally sowed at the rate of 6–8 bushels an acre, whereas in the best parts of that country, and throughout England generally, 3–4 bushels is considered a full seeding. Needless to say that the size and quality of the seed should be taken into account. In the case of oats, for instance, many of the newer varieties are distinguished by very large grain, and consequently there is a smaller number of grains in a bushel, than is the

case with certain other varieties. This, to some extent, accounts for the necessity of sowing some of these new oats very thickly. Seed that is well ripened and of high germinative capacity may, of course, be sowed more thinly than seed of poorer quality.

In the case of cereals, the great danger of sowing too thickly is laying or lodging, for the reason already given in discussing the subject of drilling, namely, that the greater the number of plants on a given area, the more completely are the sun's rays excluded from reaching the lower part of the straw, with corresponding reduction in lignification, and therefore with reduced power to stand erect. But within reasonable limits thick seeding has its advantages. In diminishing lignification it results in the production of straw that is of superior feeding value; and it is possibly to some extent owing to the large quantity of seed that Aberdeenshire farmers use per acre that the oat-straw of that country has such high feeding value. Then, again, if straw is to be used for textile purposes, such as making hats, horse collars, and the like, it is not desirable to have it much lignified, because it is more brittle and therefore less easy to manipulate. Where, therefore, straw

is grown expressly for weaving, the seeding is relatively dense. The most important textile fibre grown in the British Isles is flax, and if it is the intention to work up the product into linen, a larger quantity of seed is used than if the object is the production of linseed.

The density of the stocking, if not the quantity of seed, has great influence upon the quality of such roots as swedes, mangolds, and sugar beet. These roots are all valuable for the sugar that they contain, and it is found that the percentage of sugar is lower in large roots than in small ones. In the case of swedes and mangolds a superior quality of root may not compensate for much reduction in the yield; but in the case of sugar beet it is the custom to cultivate the crop in such a way that small-sized roots are produced, and these are not only relatively richer in sugar, but, collectively, give a larger output of sugar per acre.

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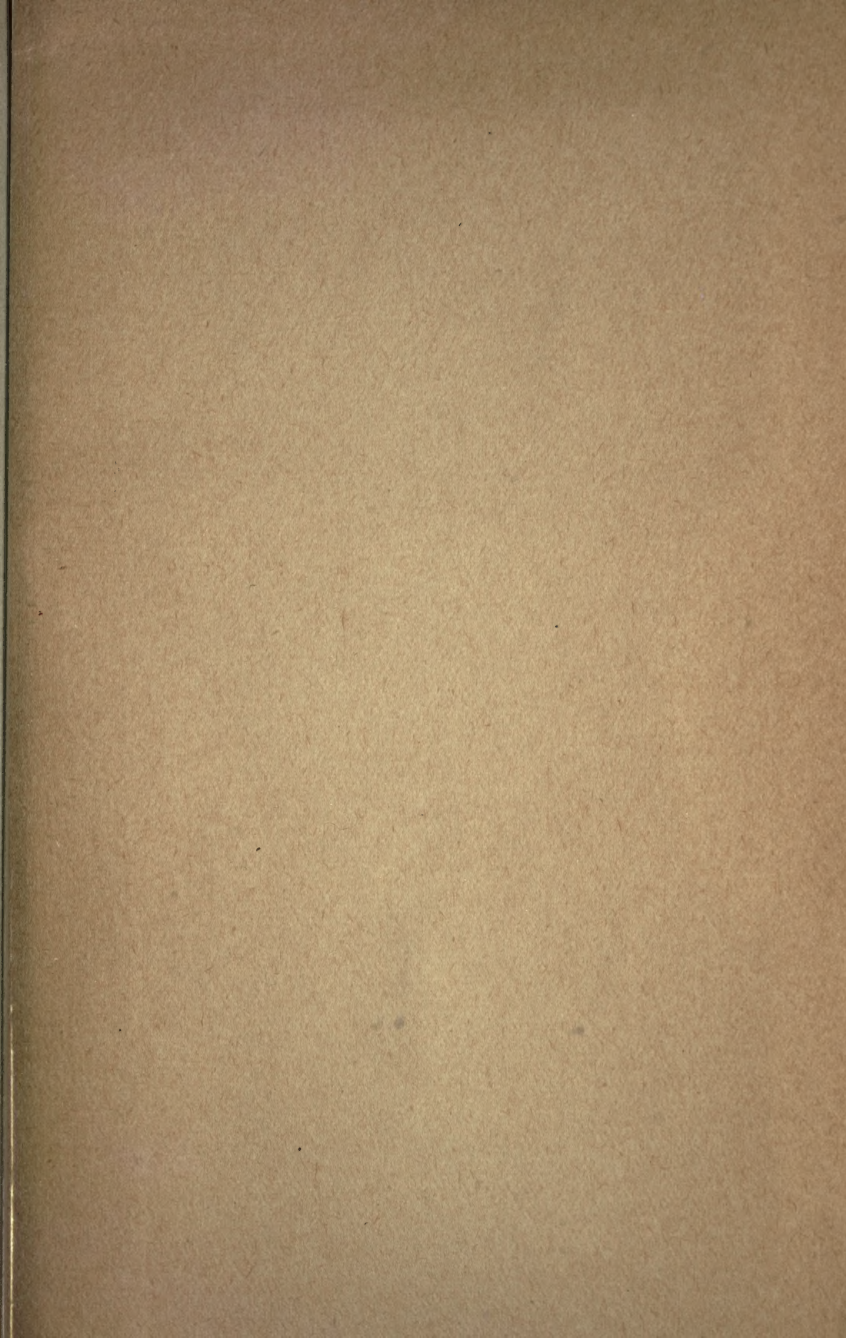
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